GULF CANADA LIMITED

RESEARCH AND DEVELOPMENT DEPARTMENT
SHERIDAN PARK, ONTARIO, CANADA

EVALUATION OF COMBUSTION OPTIONS FOR ANTHRACITE UTILIZATION

FINAL REPORT
1985-1986

by

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1. SUMMARY

The primary objective of this research program is to evaluate the effect of reactive thermal coals on anthracite combustion by thermogravimetric analysis (TGA).

In order to compare all the TGA combustion profiles on a common basis, several combustion temperatures are defined from the primary and derivative curves using a standardized procedure. The onset temperature of combustion defined in this manner, in particular, provides a good reference point for comparison, because it eliminates all the complications caused by water evaporation, oxidation and thermal degradation occurring in the initial stage of combustion. While this temperature should be correlated to the ignition temperature commonly used in combustion terminology in future study, the definition of this onset temperature has helped greatly in the interpretation of the data obtained in this study.

An earlier Gulf Canada study indicated that the combustion temperatures of anthracite can be lowered by blending with a high volatile coal such as Goodrich coal. It has been found in this study that when anthracites are mixed with reactive thermal coals of no common combustion temperature range, these thermal coals have little effect on the combustion temperatures of the resultant mixtures. Further experiments will be required to establish the synergistic effects of thermal coals with common combustion temperatures.

In conjunction with the combustion profiles, volatile release profiles give good indications of the relative reactivity of the coals under study; and CO_2 evolution profiles provide back-up information on TGA combustion profiles. TGA combustion profiles also compare very well with the data obtained from differential scanning calorimetry.

The results of this study have revealed an important criterion for selecting these thermal coals and prepared the ground work for future studies.

2. INTRODUCTION

This report describes work performed during 1985-86 on D.S.S. Contract No. OSQ85-00076, "Evaluation of Combustion Options for Anthracite Utilization". This study is limited to combustion evaluation of anthracite and coal mixtures by thermogravimetric analysis (TGA). The research contract consists of three tasks and the work statement of these tasks is attached in Appendix 1.

The main objective of this research program is to evaluate the effect of reactive thermal coals on anthracite combustion, under the environment of a pulverized firing system. The specific objectives of this research program are:

- To analyze the coal samples used in this research program (Tasks 1 and 2)
- To determine the volatile release profile of coal samples (Task 3)
- To determine the combustion temperatures of individual coals and their mixtures (Task 3)
- To determine the off-gas composition or carbon dioxide evolution profile in combustion evaluation (Task 3)
- To investigate the effect of micronized grind on combustion (Task 3)
- To provide supporting data by carrying out Differential Scanning Calorimetry (DSC) on selected samples (Task 3)
- To assess experimental results and prepare a final report (Task 3)

Activity and progress in all tasks are discussed in detail in this report.

3. INSTRUMENTATION AND SAMPLE PREPARATION

The thermal analysis work was carried out using an Omnitherm 25TG950 thermogravimetric module supervised by a DuPont 1090 Thermal Analyzer based system. The 950 TGA module operates simultaneously in the primary and derivative modes. Experimental work on DSC was carried out using the 910 DSC module. The 1090 base unit performs module programming and control as well as data acquisition and analysis using a DuPont 1091 dual disk memory unit.

A Carle Model 530 CGC was physically interfaced to the TGA module such that the gases evolved during a run were presented to the gas chromatograph for analysis. The GC was programmed for cyclic analysis in such a manner as to allow sequential CO_2 measurements to be produced throughout the duration of the TGA experimental run. This then represents a CO_2 measurement at every 25°C at a heating rate of 5°C/min. The low heating rate of 5°C/min. was used in this program to gain higher resolution in the thermograms.

The TGA data was acquired and subsequently analyzed off-line on the DuPont 1090 using DuPont TGA software. The carbon dioxide profiles were generated on an IBM PC under Energraphics. The GC sampling times were converted to TGA run temperatures using a temperature vs. time plot generated by the DuPont 1090 for each run.

Coal mixtures were prepared by carefully weighing individual coals, and mixing the components thoroughly using a mechanical shaker for no less than one hour.

4. COAL QUALITY

A simulated clean coal from Mt. Klappan (1 kg) and clean coals from Coal Valley (1 kg) and Obed Marsh (1 kg) were obtained for this research program. The Coal Valley sample (CV) and the Obed Marsh sample (OM) were prepared to conventional grind (250 μmxo). The Mt. Klappan sample was subdivided and prepared in a conventional grind (A1) and a micronized grind (A2, 45 μmxo).

Samples CV, OM and A1 were subsequently analyzed by Loring Laboratories Ltd. in Calgary for proximate analysis, ultimate analysis, calorific value, and mineral analysis of ash (Tables 1 and 2). Sample A2 was also examined for proximate analysis to confirm its quality. Samples CV, OM, and A1 were further analyzed for their maceral components by David E. Pearson & Associates Ltd. in Victoria (Table 3).

Proximate analyses of all these samples were also carried out by thermogravimetric analysis (Table 4). The data obtained by TGA method are in good agreement with those from ASTM specifications. Thermograms of proximate analysis on all these samples are attached in Appendix 2.

The results of coal quality data show that anthracite samples are very low in volatile matter, and consequently very high in fuel ratio (FC/VM). The somewhat higher residual moisture content for sample CV is believed to be due to the sample history and should not be considered as a typical value. A typical residual moisture value for Coal Valley is about 5%.

5. TGA & DSC EVALUATIONS OF COAL AND COAL MIXTURES

This section discusses the results of the main task of this research program. Coal samples were examined for volatile release profile, combustion profile, and carbon dioxide profile in this task. A limited number of DSC runs was also performed to gain some insight of the combustion process, although they were not required in this research contract. The symbols used to define combustion temperatures and the results of all these studies are separately discussed in the following sections.

5.1 Notation

Various combustion temperatures are used in coal combustion studies (1,2,3,4). Since this program was carried out with the objective to compare combustion profiles on a common basis, there was no attempt to correlate combustion temperatures defined in this report with others commonly referred in coal combustion.

All the combustion temperatures defined in this report can be obtained by a standardized procedure.

The symbols and their definitions used for coal combustion temperatures in this report are described below. A specimen thermogram showing all these temperatures is shown in Figure 1.

T_o Initial temperature of combustion. Defined as the last temperature at which the derivative curve crosses the base line.

T_{xo} Onset temperature of combustion. Obtained at the intersection of tangent line drawn at the first point of inflection and the tangent line drawn at T_o, on the primary curve.

T_{25}, T_{50}, T_{75}
Temperature of 25%, 50%, and 75% combustion of carbonaceous material respectively, (i.e. dry ash free basis of coal).

T_{xc} Temperature of complete combustion. Obtained at the intersection of tangent line drawn at the last point of inflection and the tangent line drawn at constant weight at elevated temperature, on the primary curve.

$T_i(1)$ Temperature of first inflection point on the primary curve.

$T_i(2)$ Temperature of last inflection point on the primary curve.

5.2 Volatile Release Profile

Volatile release profiles determined by thermogravimetric method for individual coals are attached in Appendix 3. Each profile consists of a curve and a summary table. These profiles were obtained at a heating rate of 5°C/min, a flow rate of nitrogen of 40 mL/min, using a sample weight of 25-30 mg.

The inert atmosphere used in volatile release profile determinations prevents the coal from oxidation and combustion. The loss of mass at various temperatures, except for those due to water removal, can be considered solely caused by thermal degradation of the coal samples. The extent of mass loss, therefore, is a direct indication of the "reactive" species present in a particular coal sample.

A review of the volatile release profiles in Appendix 3 shows that there are significant differences between bituminous coals and anthracite. Bituminous coals began to lose mass at a lower temperature and at a faster rate, resulting in a higher weight loss at various temperatures covered in this evaluation. While the final mass loss at 900°C, which is the temperature at which volatile matter determination is carried out in ASTM specification, agrees well with the volatile matter content in all cases, the release of volatile matter at lower temperatures are more crucial in determining the combustion temperatures of coal. Table 5 summarizes the mass loss at various temperatures for Coal Valley, Obed Marsh and anthracite of different grind. The mass loss at 300-500°C range for bituminous coals are substantially higher than those from anthracites.

The effect of micronized grind on volatile release is also shown in Table 5 by comparing the results observed for samples A1 and A2. At all temperatures, the micronized grind (A2) shows a larger mass loss than the conventional grind (A1). The effect of increased release of volatile matters on combustion temperatures is discussed in the next section.

Numerous attempts were made to determine the composition of the off-gas generated in the volatile release profiles. Volatile matters released at lower temperatures (e.g. 300-400°C) are usually only a fraction of the sample weight which is typically about 30 mg; and they are further diluted by the large flow rate

of nitrogen gas. The gas composition determined, therefore, showed large concentration of nitrogen and trace amounts of methane, ethane, propane and carbon dioxide. In order to increase the reliability of the gas analysis, volatile release profiles were carried out with larger sample weight (≃100 mg), higher heating rate (≃20°C/min) and lower nitrogen flow rate (≃20 mL/min) in order to reduce the dilution. While some improvements were observed, the reliability of the results is still not satisfactory. Different technique and/or instrumentation are required to solve this problem.

5.3 Combustion Profiles

Combustion profiles of coals and coal mixtures were studied in detail in this research program. All the combustion profiles were determined under the same operating conditions: 5°C/min heating rate, 40 mL/min of air flow rate, using 30-40 mg of coal samples. These profiles are attached in Appendix 4. Each profile normally consists of a thermogram and a summary table. The enhanced sections of the thermogram are also shown for some selected samples.

Combustion profiles obtained by thermogravimetric method covering a temperature range from ambient to 800°C contain a great deal of complex information: water removal, oxidation, thermal degradation, and combustion. At elevated temperatures above 800°C, thermal decomposition of minerals resulting in a net gain or loss of mass are also registered.

The most difficult task in analyzing TGA combustion profiles is to identify the onset temperature because it is greatly complicated by the occurrences of mass losses due to water removal, oxidation, and volatile release. T_o, as defined in Section 5.1, is therefore not a reliable benchmark for comparing the initial combustion temperatures. T_{xo}, which is located by drawing tangent lines at T_o and the first inflection point on the primary curve, is well into combustion and therefore is more kinetically meaningful and more logical for comparison purposes.

T_{xo} determined for all the coal samples in this study typically represents 5-10% mass loss. Considering the fact that there are weight losses due to water removal and volatile matter release, T_{xo} appears to be the ideal temperature for comparing onset temperatures of combustion, because they can be determined by a well defined procedure. T_{xo} is therefore used in analyzing all the combustion profiles.

Based on the notation outlined in Section 5.1, a combustion profile can be broadly subdivided into areas of pre-combustion, combustion, and post-combustion. Post-combustion deals with the decomposition of minerals at elevated temperatures and is of little interest in this study. The precombustion stage covers the temperature range between ambient to T_{xo}, and combustion stage is confined within the temperatures of T_{xo} and T_{xc}. These stages are shown in Fig. 1 and discussed in the following sections.

5.3.1 Pre-combustion

When the temperature of a coal sample is gradually increased in thermogravimetric analysis up to temperature T_{xo}, water in coal will be evaporated, "reactive" species will be driven off, and surface oxidation which involves oxygen adsorption and carbon dioxide desorption will occur. The temperature at which these reactions will occur obviously depends on the coal rank, and oxidation, in particular, will also depend on the history of the coal samples.

Comparison of the combustion profiles in Appendix 4 shows that weight loss for bituminous coals in this temperature range is significantly higher than anthracites. These observations are in good agreement with those observed in the volatile release profiles. For coal mixtures, the weight loss in this temperature range is almost additive and can be calculated from the amounts of individual components.

Coal oxidation in the pre-combustion zone is shown in Figure 2. Figure 2 is an enhanced section of the combustion profile for the micronized grind anthracite (A2). The coal sample started to gain weight at ca. 240°C, reached a maximum at ca. 360°C, then began to lose weight. Between 240-360°C, oxygen was adsorbed onto coal surface and a net weight gain was observed. At temperatures above 360°C, desorption of carbon dioxide began and a net weight loss was registered. At 360°C, weight gain and loss are in balance resulting in no change of mass in the thermogram.

Coal Valley and Obed Marsh bituminous coals, however, were not observed for oxidation in this study, probably due to the sample history. The enlarged section for both Coal Valley and Obed Marsh coals in the pre-combustion zone are presented in Figs. 3 and 4.

5.3.2 Combustion

Between the temperature boundaries of T_{xo} and T_{xc}, the carbonaceous materials in coal are consumed to produce carbon dioxide and water, leaving behind the inorganic material present in the coal samples. Monitoring the carbon dioxide concentration as a function of temperature, therefore, should provide complimentary data in the evaluation of combustion profiles. The CO_2 evolution profiles are discussed in the next section.

Combustion profiles obtained for bituminous coals (CV and OM) are substantially different from those obtained for anthracite (A1 and A2). The two bituminous coals studied have a narrower combustion window (350-430°C) than those from anthracite (495-572°C). The rates of mass loss are also much higher for the bituminous coals, as shown by the thermograms in Appendix 4. This indicates that carbon in the anthracite samples are more thermally stable. This is supported by the large amount of semi-fusinite present in the anthracite sample. The combustion temperatures of individual coals and their mixtures are compared in Tables 6, 7, 8, and 9.

Combustion profiles for coal mixtures of bituminous coals and anthracites are almost additive in this study. While the individual coal shows one single inflection point, the mixtures show two inflection points at temperatures governed by the individual components. The onset temperatures for all mixtures are more or less the same as observed for the bituminous coal, and the completion temperatures are practically the same as indicated by the anthracite component. The additive nature of the coal mixtures is further shown by examining the weight at the two inflection points of the combustion profiles. The ratio of weights at these inflection points matches very well with the compositions of the coal mixtures.

The onset temperature, completion temperature, and temperature at various levels of combustion are plotted against the composition of coal mixtures in Figures 5 to 8 inclusive. These data show that synergism was not achieved in lowering the onset and completion temperature of the more inert component.

The results of this study, however, are different from the result of a previous in-house study. In the previous study, Goodrich bituminous coal was used as the more reactive component. This thermal coal has an onset temperature of ca. 360°C and a completion temperature of ca. 550°C. Blending this coal with Mt. Klappan anthracite shows that while it was not able to lower the completion temperature, the onset temperature of anthracite was reduced. Figure 9 shows the coal combustion temperature as a function of composition in coal mixtures of anthracite and this Goodrich thermal coal.

The difference in results of this study and the previous study can be explained by the temperature range of combustion for each individual coal. Figure 10 shows the combustion temperature range for Obed Marsh (OM), Coal Valley (CV), conventional grind anthracite (A1), micronized grind anthracite (A2), Goodrich thermal coal, and another anthracite from drill core. It is clear from this figure that while the Goodrich thermal coal and anthracite have common range in combustion temperatures, there is a big gap in combustion temperatures between Obed Marsh or Coal Valley and the anthracite component.

Finally, the effect of micronized grind on combustion temperatures is shown in Figure 11. The micronized grind requires lower temperatures for various levels of combustion. This is believed to be caused by the improved release of volatile matters, as discussed in Section 5.2.

5.4 Carbon Dioxide Evolution Profile

Carbon dioxide evolution profiles were monitored for all the experiments carried out for combustion evaluation. All CO_2 evolution profiles are attached in Appendix 5. For the series of Coal Valley and anthracite of conventional grind, the CO_2 profiles are shown in separate figures for each mixture in the appendix. For the rest of the series, the CO_2 profiles of all the mixtures in each series are shown in the same figure to provide a better comparison.

The carbon dioxide evolution profiles for Coal Valley and anthracite of conventional grind are shown in Figure 12. The relative concentrations of CO_2 are plotted against combustion temperature.

These profiles are very similar to the derivative curves of the combustion profiles. It should be noted that some carbon dioxide above the background level was detected at temperatures at about 200°C for the Coal Valley coal; but for anthracite this was detected at temperatures above 300°C. The fact that the onset temperature of CO_2 evolution precede those from combustion reflects the presence of the processes of carbon dioxide desorption from oxidation and decarboxylation of coal.

CO_2 evolution profiles provide supporting data for the combustion profiles in comparing the order of combustion temperature. The additive nature of coal mixtures are again shown in the evolution profiles in Appendix 5.

5.5 DSC Profile

A limited number of samples were evaluated by differential scanning calorimetry to provide supporting data to the combustion profiles. DSC measures heat flow as a function of temperature. DSC profiles for four individual coals and two coal mixtures are attached in Appendix 6.

The DSC data basically confirm that the coal mixtures were combusted as individual components, because of the lack of common combustion temperature range. Table 10 compares the onset combustion temperatures by TGA and DSC, and Table 11 compares the temperatures of maximum mass loss and maximum heat flow determined by these two methods. It is observed that in both cases there are a high degree of correlation.

6. CONCLUSIONS

6.1 The volatile release profiles provide basic information on the amount of "reactive" components present in a coal sample. Bituminous coals begin to release volatile matter at a lower temperature, and at a faster rate than anthracites. Volatile release can also be increased by using a sample of micronized grind.

6.2 T_{xo}, as defined and used in this report, is a good reference point for comparing onset temperature of combustion. It eliminates the complications due to water removal, oxidation, and volatile release from coal.

6.3 Combustion profiles for bituminous coal and anthracite are substantially different. Combustion profiles of coal mixtures of components with different combustion temperature ranges are practically additive. Mixture compositions can be calculated from the profiles of coal mixtures.

6.4 Initial and final combustion temperatures of an inert coal cannot be lowered by a reactive coal with no common range of combustion temperature. However, it has been observed in a previous in-house study that combustion temperatures of inactive coal were lowered by a more active component with common combustion temperature range. The effect of using a reactive coal with certain common combustion temperature range on the combustion of an inert coal should be further studied.

6.5 Coal of micronized grind demands a lower temperature (ca. 10°C) for combustion.

6.6 CO_2 evolution profiles are substantially similar to the combustion profiles determined by TGA method. The order of combustion temperatures determined by both methods is the same, although the onsets from CO_2 profiles always precede those from TGA. This is caused by CO_2 generations from desorption and decarboxylation.

6.7 DSC provides further support for TGA combustion profiles. There is an excellent correlation between the onset temperatures determined by both methods. The temperatures of maximum heat flow from DSC and the inflection temperature from TGA are also in good agreement.

7. RECOMMENDATIONS

The work reported here is based on the results of coal mixtures from components with entirely different combustion temperature range. Other thermal coals, particularly those with certain common combustion temperature range as the inert component, should be carefully studied before a definite conclusion can be made. The following work is recommended.

7.1 Carry out TGA study on mixtures with components with certain common combustion temperature range (anthracite and Goodrich thermal coal for example). These mixtures should provide a better understanding on the effect of blending.

7.2 Carry out DSC study concurrent with TGA work to better define combustion temperatures for comparison.

7.3 Carry out bench scale combustion evaluation on coal mixtures to determine carbon burn out for supporting data.

8. REFERENCES

1. Longanbach, J.R. and Sass, A., Fuel, 1975, Vol 54, p 29.

2. Marinov, V., J. Thermal Anal, 7, 1975.

3. Ciuryla, V.T., Weimer, R.F., Bivans, D.A., Motika, S.A., Fuel, 1979, Vol 58, p 749.

4. Byers, R. W. et al., "Fuel evaluation Using Differential Thermal Techniques", Paper presented at Coal Technology '78, Houston, Texas, 1978.

TABLE 1

PROXIMATE AND ULTIMATE ANALYSES OF COAL SAMPLES

	Mt. Klappan		Coal Valley	Obed Marsh
	A1*	A2**		
% Residual Moisture (RM)	3.2	2.7	9.3	6.6
% Ash (Ash)	9.8	10.7	10.8	10.3
% Volatile Matter (VM)	6.3	6.9	30.3	37.4
% Fixed Carbon (FC)	80.7	79.7	49.6	45.7
Calorific Value (cal/g)	7233	--	6018	5980
Fuel Ratio (FC/VM)	12.8	11.6	1.6	1.2
% Carbon	79.6		64.6	61.4
% Hydrogen	2.3		3.6	3.6
% Nitrogen	0.9		0.9	1.3
% Sulfur	0.5		0.2	0.4
% Ash	9.8		10.8	10.3
% RM	3.2		9.3	6.6
% Oxygen (by difference)	3.7		10.6	16.4

* Conventional grind (250 µmxo)
** Micronized grind (45 µmxo)

TABLE 2

MINERAL ANALYSIS OF ASH FROM COAL SAMPLES

Wt %	Mt. Klappan	Coal Valley	Obed Marsh
SiO_2	64.8	59.8	60.3
Al_2O_3	21.5	17.3	20.9
TiO_2	1.2	0.4	0.4
Fe_2O_3	1.9	3.1	1.6
CaO	2.4	10.4	9.2
MgO	1.5	1.2	1.3
Na_2O	1.4	0.6	0.3
K_2O	1.1	0.6	0.5
P_2O_5	1.3	0.7	0.2
SO_3	0.5	3.9	3.5

TABLE 3

MACERAL ANALYSIS OF COAL SAMPLES
(ASH FREE BASIS)

	Mt. Klappan	Coal Valley	Obed Marsh
Reactive Components			
Vitrinite	73.3	64.2	81.1
Exinite	-	1.4	3.2
Reactive Semifusinite	-	8.5	6.7
	73.3	74.1	91.0
Inert Components			
Macrinite	1.0	3.0	1.1
Inert Semifusinite	24.3	13.5	4.2
Fusinite	1.4	2.9	2.6
Inert Odetrinite	-	6.3	1.1
Oxidized Coal	-	0.2	-
	26.7	25.9	9.0

TABLE 4

PROXIMATE ANALYSIS OF COAL BY THERMOGRAVIMETRIC ANALYSIS (TGA)

	Mt. Klappan A1*		Mt. Klappan A2**		Coal Valley			Obed Marsh	
% Residual Moisture (RM)	2.9	3.1	1.9	1.0	7.5	3.4	5.3	5.8	5.1
% Ash (Ash)	9.8	7.8	10.3	10.6	8.5	11.7	10.3	11.5	11.0
% Volatile Matter (VM)	5.0	5.3	6.2	6.1	31.6	31.9	30.8	33.3	33.6
% Fixed Carbon (FC)	82.3	83.7	81.6	82.4	52.5	53.0	53.6	49.4	50.3

* Conventional grind (250 µmxo)

** Micronized grind (45 µmxo)

TABLE 5

SUMMARY OF MASS LOSS AT DIFFERENT TEMPERATURES
IN VOLATILE RELEASE PROFILES

	% Wt. Loss (Cumulative) at				
Sample	200°C	300°C	400°C	500°C	900°C
A1	-	0.7	1.0	1.5	7.3
A2	-	1.1	1.5	2.2	8.5
CV	3.5	5.0	9.0	20.5	35.2
OM	4.0	5.5	10.0	23.0	39.0

TABLE 6

SUMMARY OF TGA DERIVED COMBUSTION TEMPERATURES
A1 AND CV (ANTHRACITE 250 μmxo AND COAL VALLEY COAL)

Sample	Composition (% anthracite)	T_{xo}	T_i	T_{xc}	T_o	T_{25}	T_{50}	T_{75}
#8	100 (pure anthracite)	502	537	572	398	525	540	565
#7	75	396	431 538	570	274	470	530	555
#6	50	393	422 542	572	250	425	495	545
#24	25	381	410 544	573	240	410	430	505
#3	0 (pure Coal Valley)	354	376	424	228	375	395	420

TABLE 7

SUMMARY OF TGA DERIVED COMBUSTION TEMPERATURES
A2 AND CV (ANTHRACITE 45 μmxo AND COAL VALLEY COAL)

Sample	Composition (% anthracite)	T_{xo}	T_i	T_{xc}	T_o	T_{25}	T_{50}	T_{75}
#10	100 (pure anthracite)	495	519	556	363	512	526	540
#11	75	391	425 524	554	281	465	510	530
#16	50	390	420 523	554	250	425	485	530
#15	25	385	415 530	560	237	405	430	475
#3	0 (pure Coal Valley)	354	376	424	228	375	395	420

TABLE 8

SUMMARY OF TGA DERIVED COMBUSTION TEMPERATURES
A1 AND OM (ANTHRACITE 250 μmxo AND OBED MARSH COAL)

Sample	Composition (% anthracite)	T_{xo}	T_i*	T_{xc}	T_o	T_{25}	T_{50}	T_{75}
#8	100 (pure anthracite)	502	537	572	398	525	540	565
#17	75	387	416 541	569	270	465	530	555
#18	50	379	406 542	570	250	410	485	545
#19	25	376	405 547	574	237	400	420	495
#21	0 (pure Obed Marsh)	378	392	426	230	380	402	418

* 1 value for pure coal, 2 values for mixtures

TABLE 9

SUMMARY OF TGA DERIVED COMBUSTION TEMPERATURES
A2 AND OM (ANTHRACITE 45 μmxo AND OBED MARSH COAL)

Sample	Composition (% anthracite)	T_{xo}	T_i	T_{xc}	T_o	T_{25}	T_{50}	T_{75}
#10	100 (pure anthracite)	495	519	556	363	512	526	540
#20	75	381	411 520	552	266	450	518	535
#22	50	379	407 526	556	240	410	462	530
#25	25	370	399 533	563	230	395	415	490
#21	0 (pure Obed Marsh)	378	392	426	230	380	402	418

TABLE 10

COMPARISON OF ONSET COMBUSTION TEMPERATURE BY TGA AND DSC

	A1	A2	CV	OM	A1 + CV 50/50	A1 + CV 25/75
TGA (°C)	495	502	354	378	393	396
DSC (°C)	486	480	395	387	398	399

TABLE 11

COMPARISON OF COMBUSTION TEMPERATURE OF MAXIMUM MASS LOSS AND MAXIMUM HEAT FLOW BY TGA & DSC

	A1	A2	CV	OM	A1 + CV 50/50	A1 + CV 25/75
TGA* (°C)	537	519	376	392	422/542	431/538
DSC** (°C)	547	538	439	423	439/549	440/550

* Inflection temperature

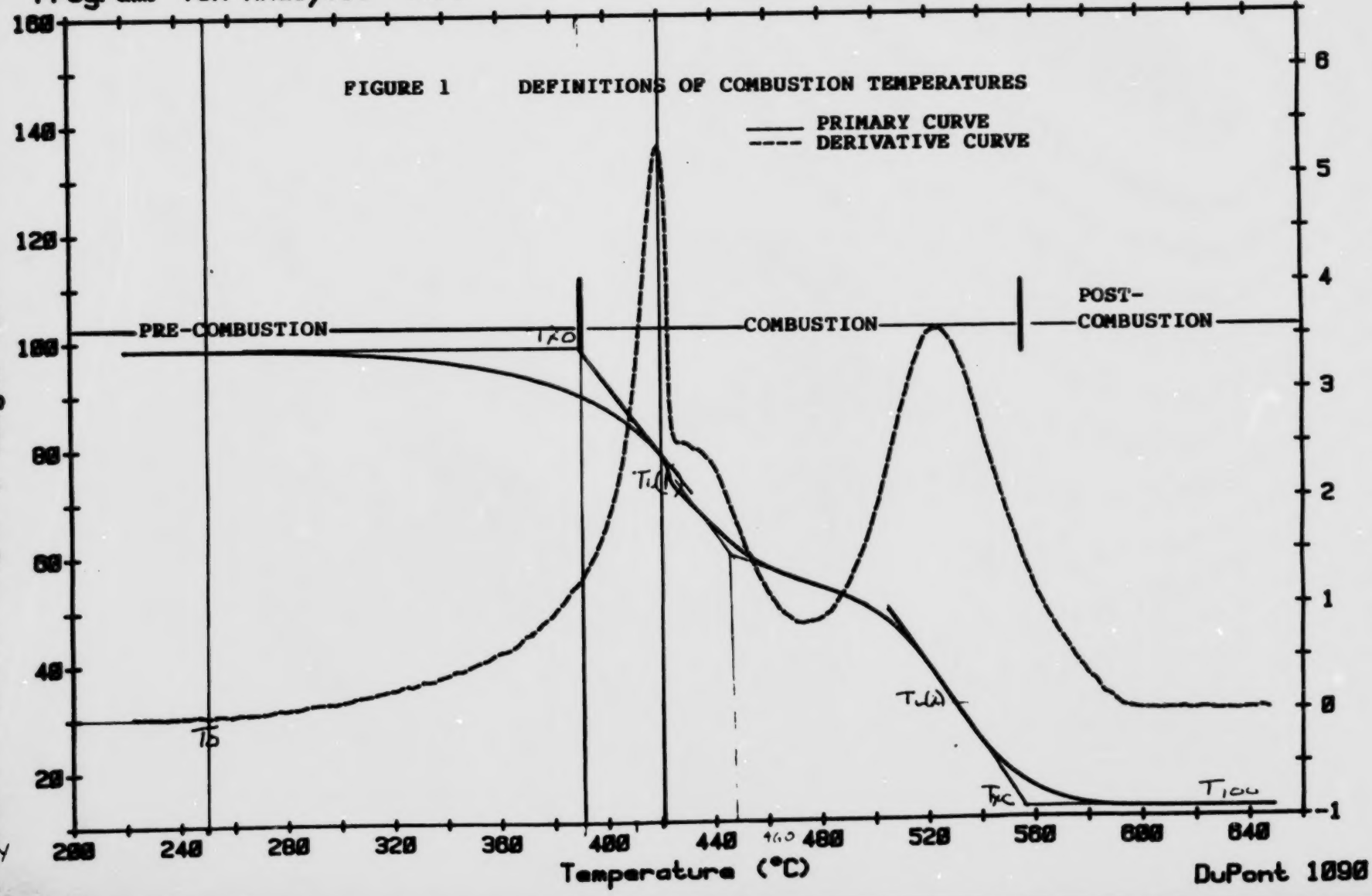
** Temperature of maximum heat flow

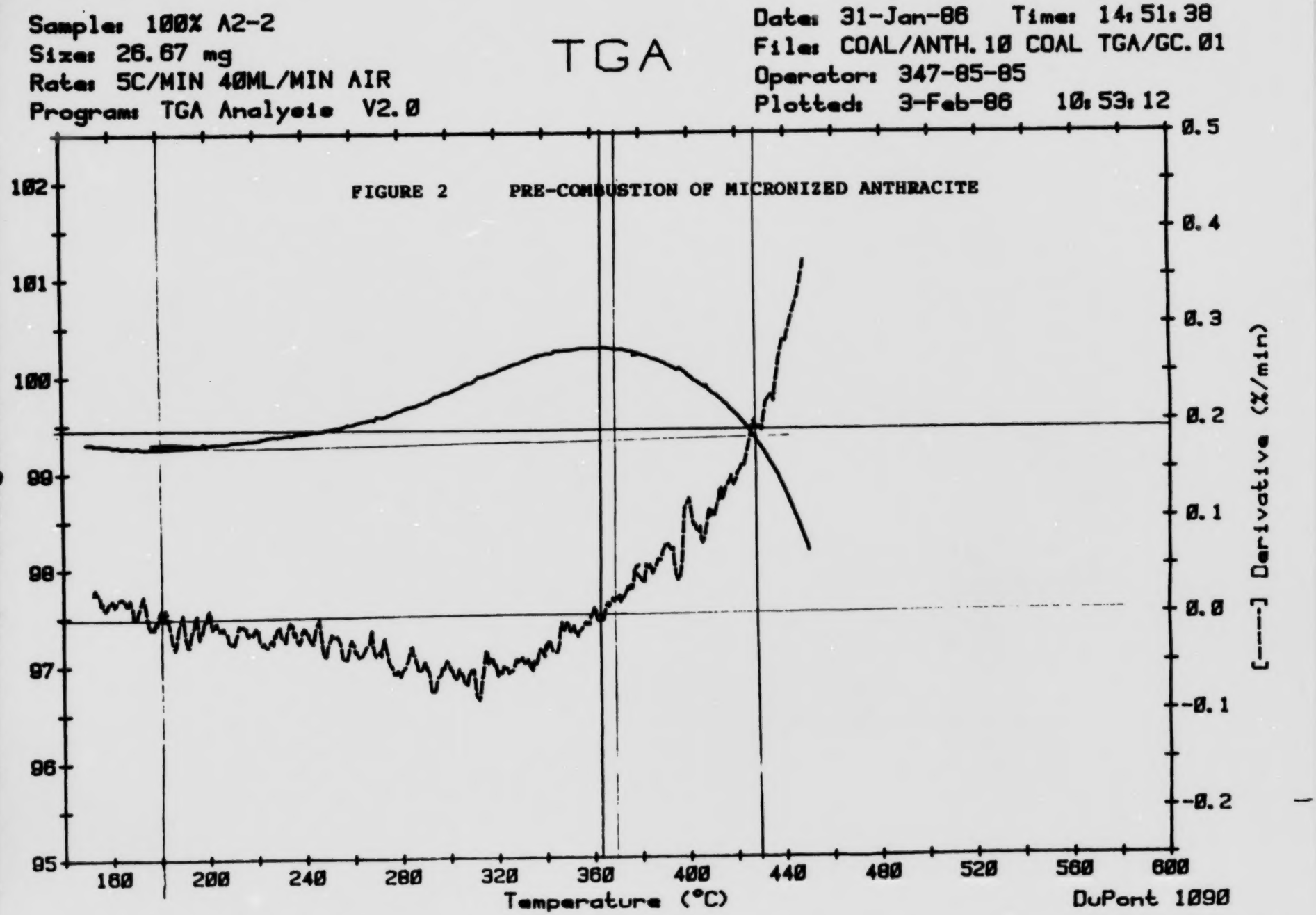
SPECIMEN THERMOGRAM

Sample: 50% A2 50% CV
Size: 34.12 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

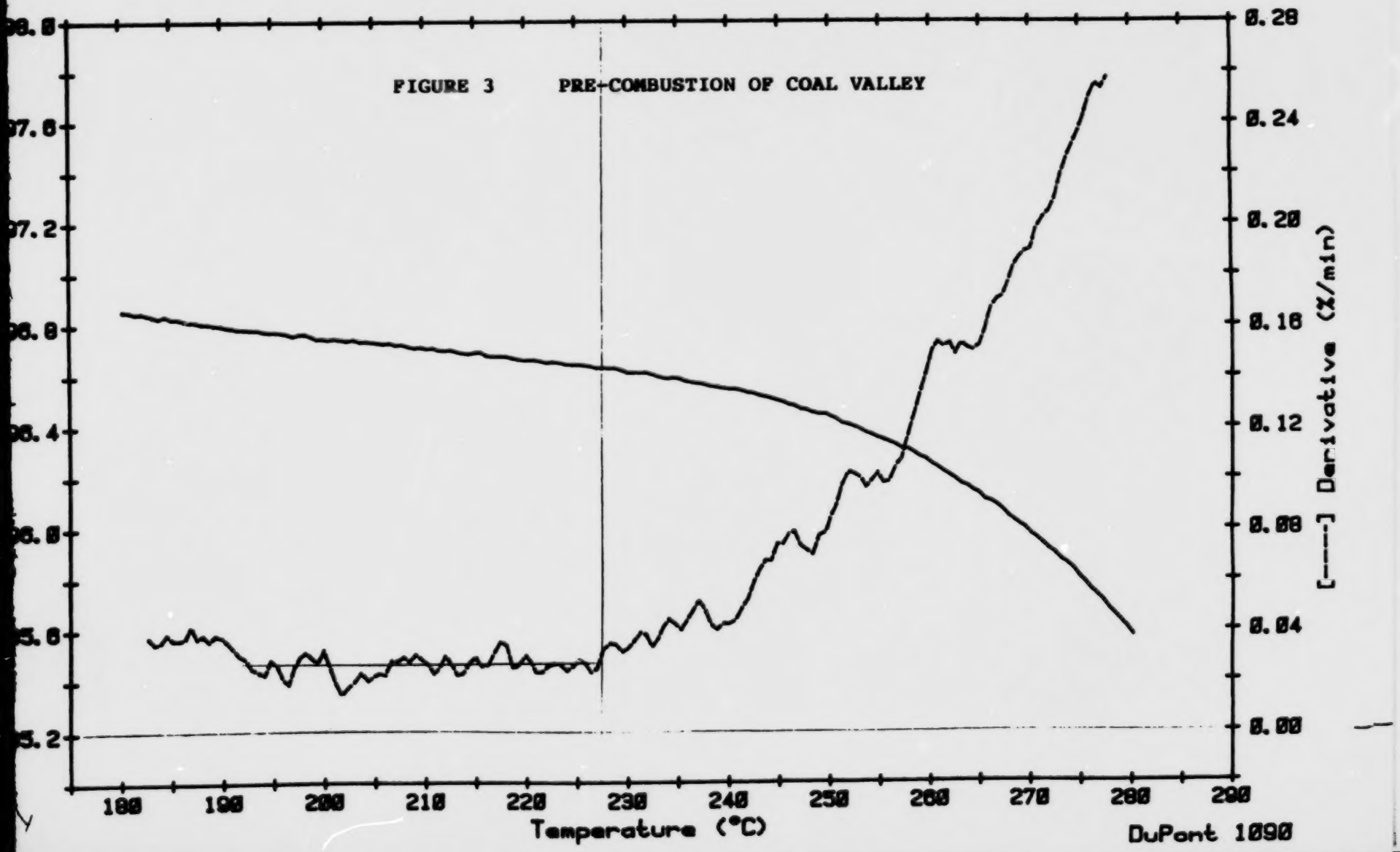
Date: 10-Feb-86 Time: 9:38:43
File: COAL/ANTH.16 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 14:41:56




Sample: 100% A2-2
Size: 26.67 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 31-Jan-86 Time: 14:51:38
File: COAL/ANTH.10 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 3-Feb-86 10:53:12
FIGURE 2 PRE-COMBUSTION OF MICRONIZED ANTHRACITE
102
101
100
99
98
97
96
95
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
[----] Derivative (%/min)
160
200
240
280
320
360
400
440
480
520
560
600
Temperature (°C)
DuPont 1090

Sample: 100% CV
Size:

TGA



Sample: 100% OM
Size: 35.59 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 13-Feb-86 Time: 8:56:54
File: COAL/ANTH.21 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 13:39:09

FIGURE 4 PRE-COMBUSTION OF OBED MARSH

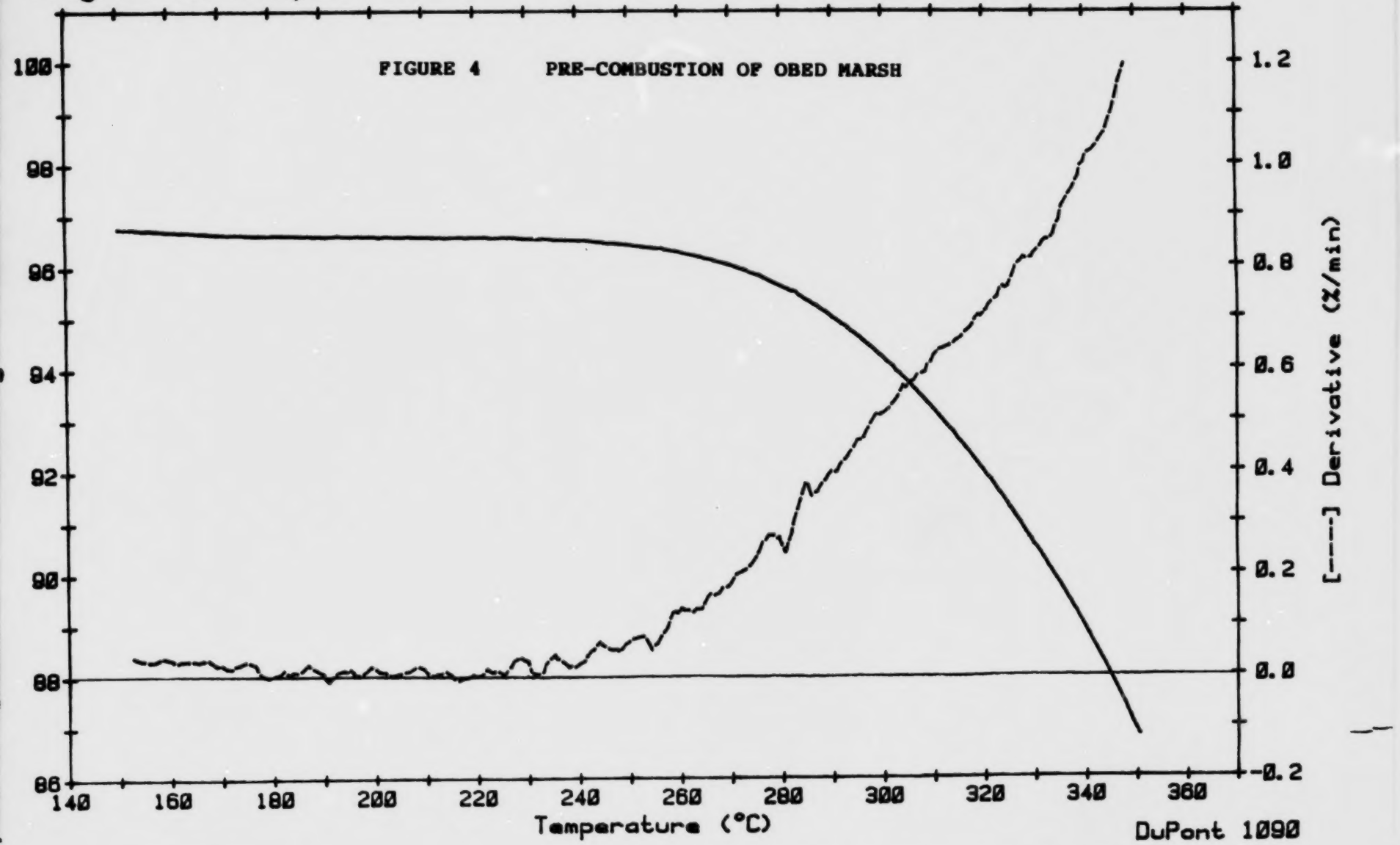


FIGURE 5

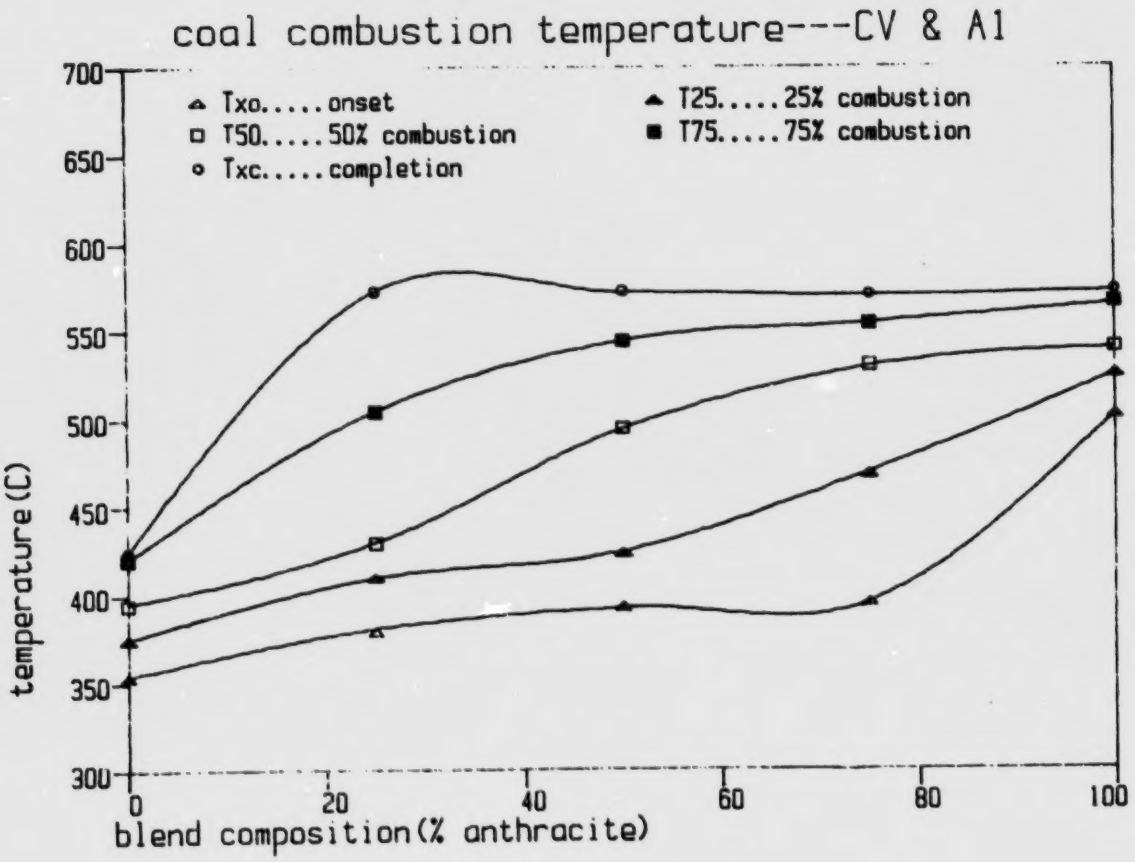

coal combustion temperature---CV & A1
Txo.....onset
T50.....50% combustion
Txc.....completion
T25.....25% combustion
T75.....75% combustion
700
650
600
550
500
450
400
350
300
temperature(C)
0
20
40
60
80
100
blend composition(% anthracite)

FIGURE 6

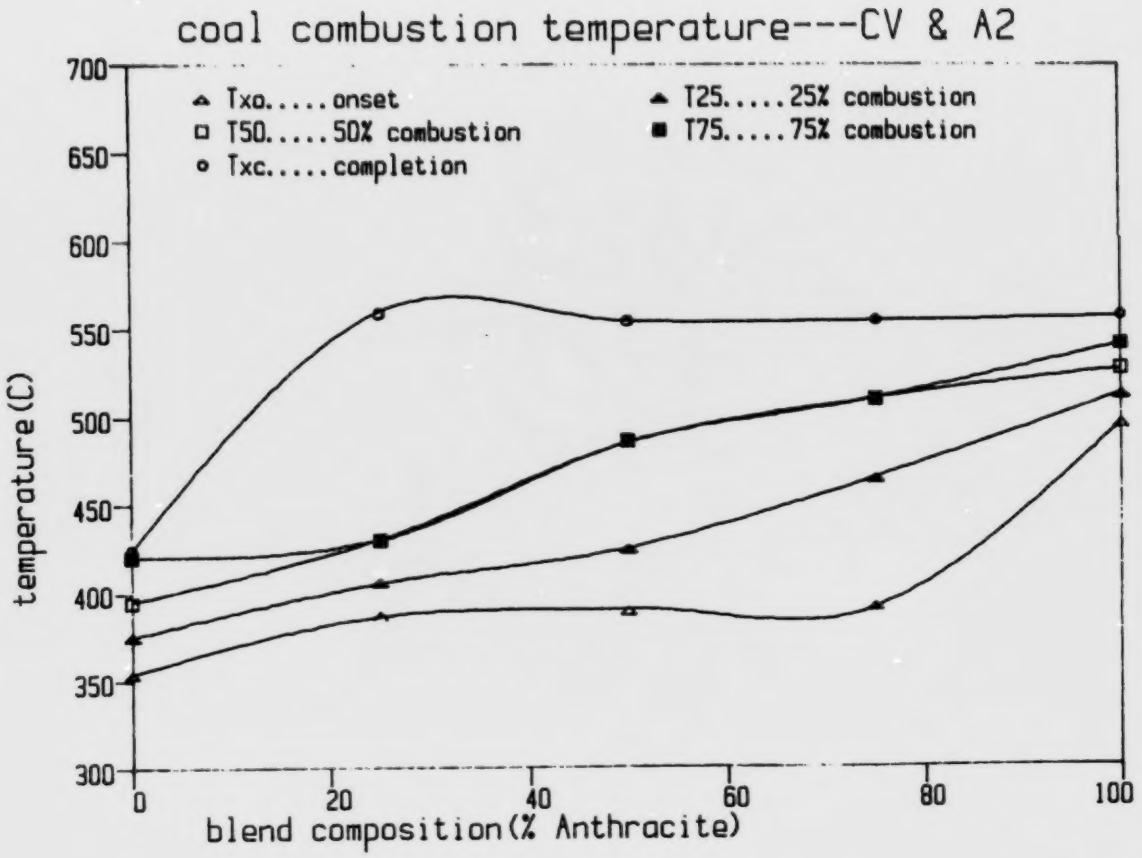

coal combustion temperature---CV & A2
Txo.....onset
T50.....50% combustion
Txc.....completion
T25.....25% combustion
T75.....75% combustion
temperature(C)
700
650
600
550
500
450
400
350
300
0
20
40
60
80
100
blend composition(% Anthracite)

FIGURE 7

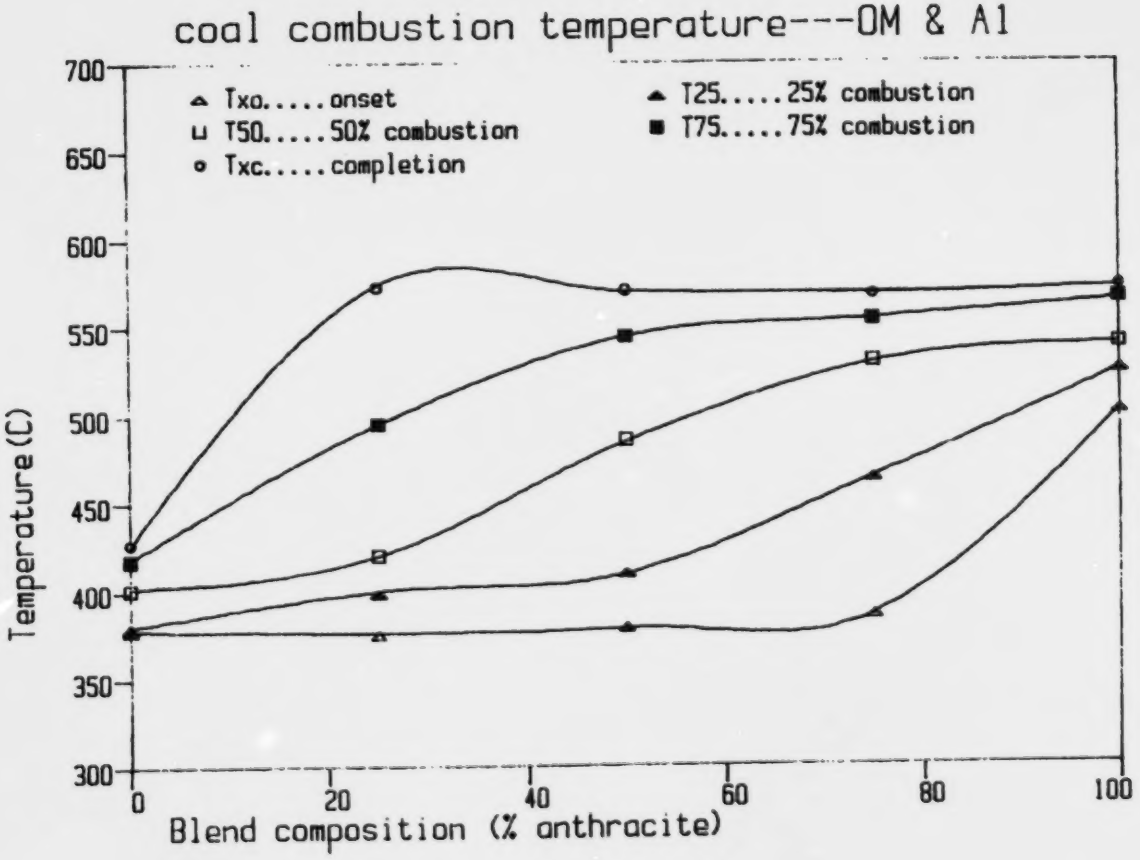

coal combustion temperature---OM & A1
Txo.....onset
T50.....50% combustion
Txc.....completion
T25.....25% combustion
T75.....75% combustion
Temperature(C)
700
650
600
550
500
450
400
350
300
0
20
40
60
80
100
Blend composition (% anthracite)

FIGURE 8

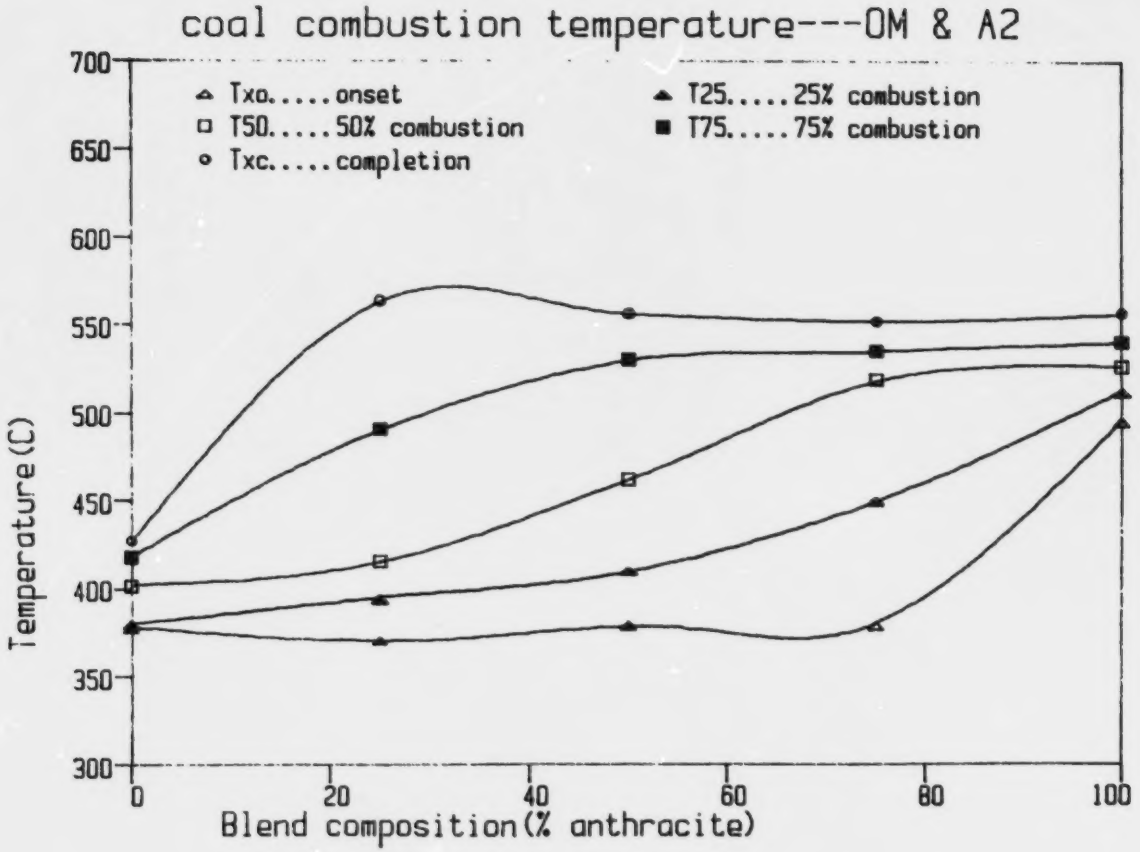

coal combustion temperature---OM & A2
Txo.....onset
T50.....50% combustion
Txc.....completion
T25.....25% combustion
T75.....75% combustion
Temperature(C)
700
650
600
550
500
450
400
350
300
0
20
40
60
80
100
Blend composition(% anthracite)

FIGURE 9

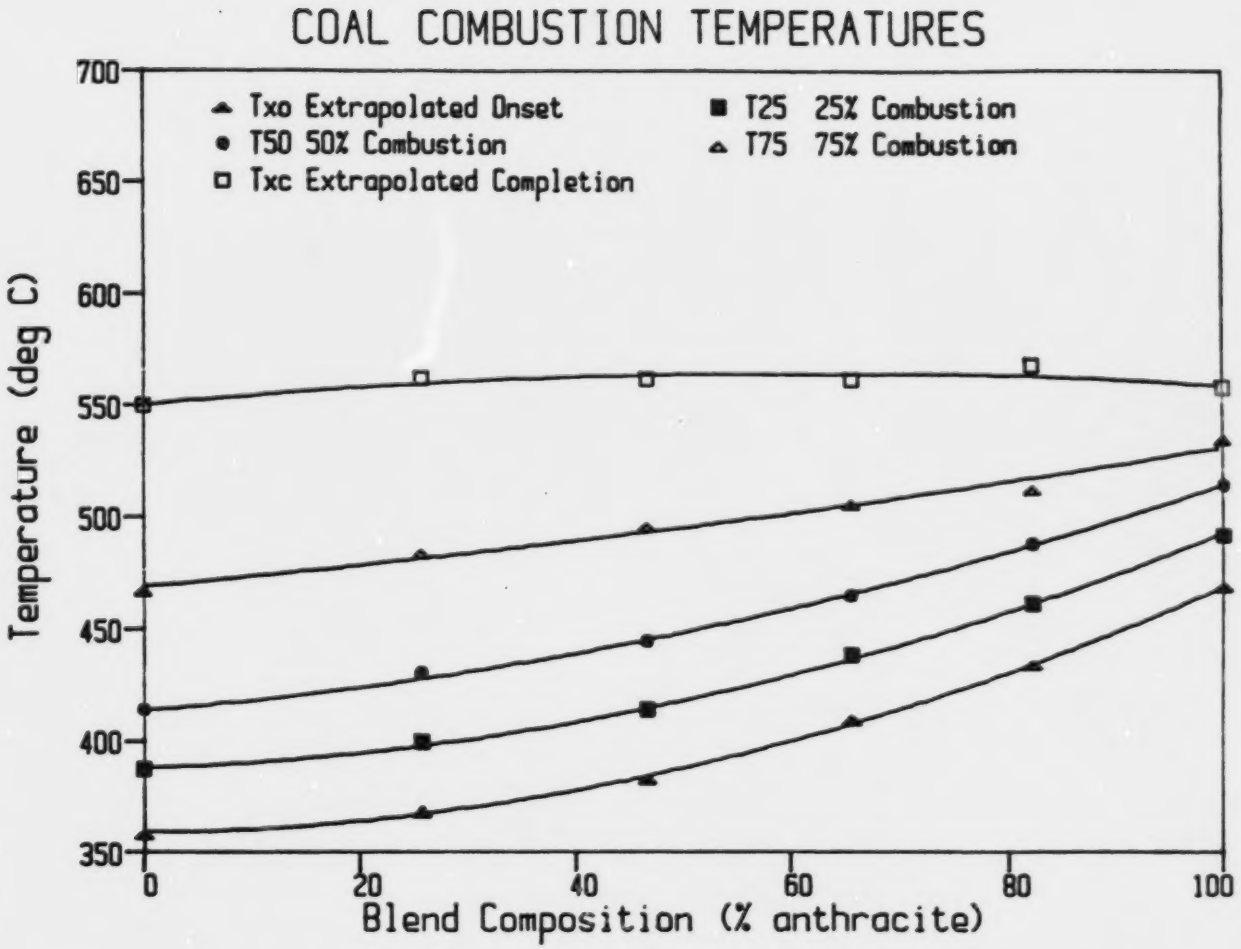


Figure 14. Plot of combustion temperatures as a function of blend composition.

FIGURE 10

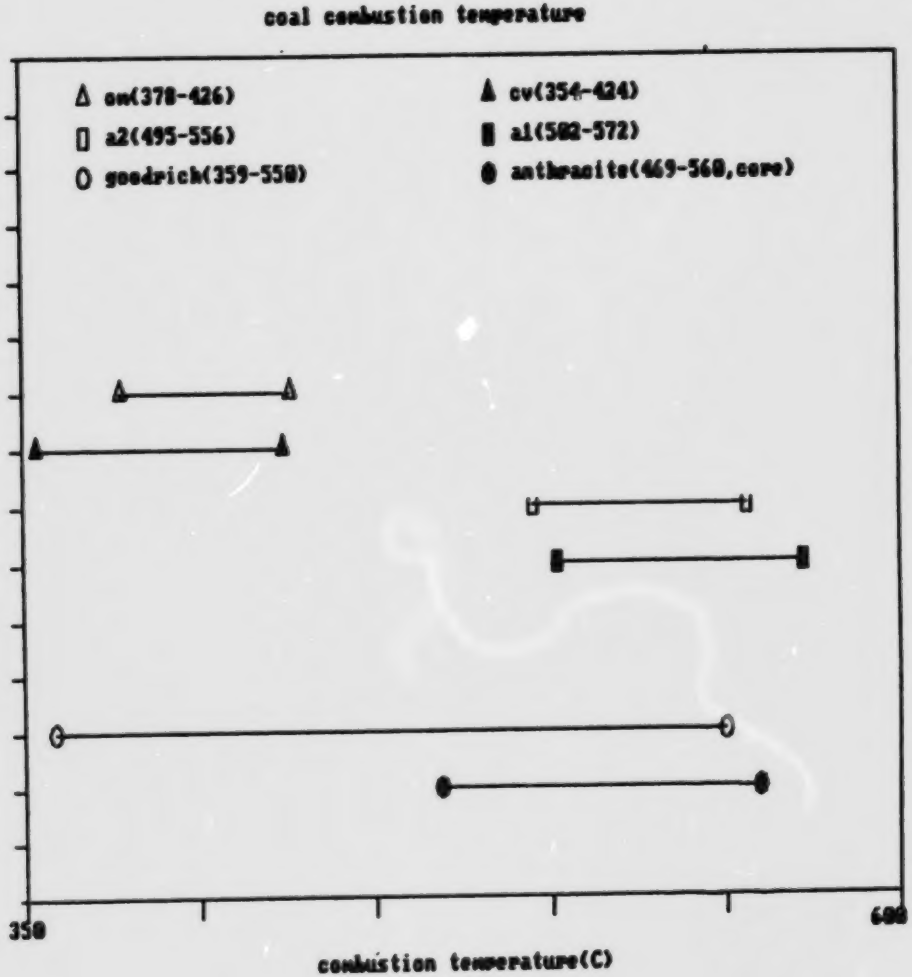

coal combustion temperature
on(378-426)
a2(495-556)
goodrich(359-550)
cv(354-424)
a1(502-572)
anthracite(469-560,core)
350
600
combustion temperature(C)

FIGURE 11

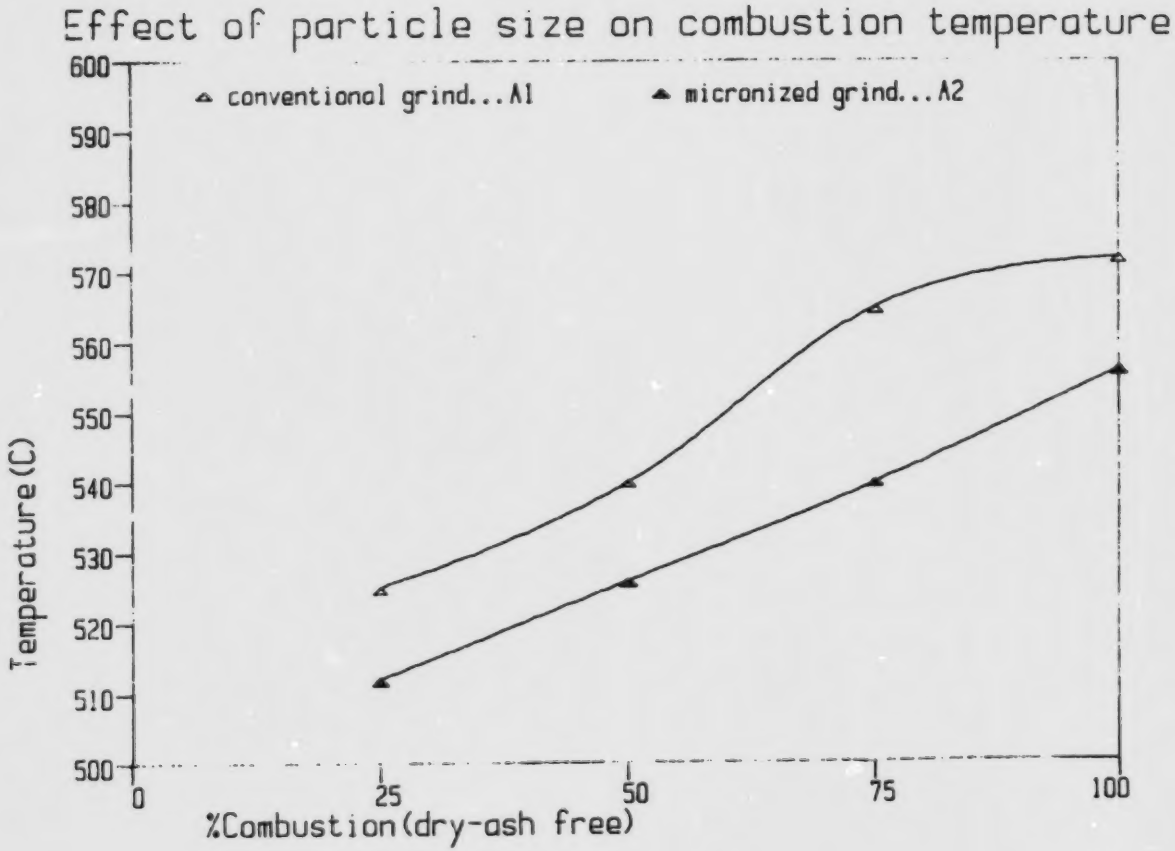
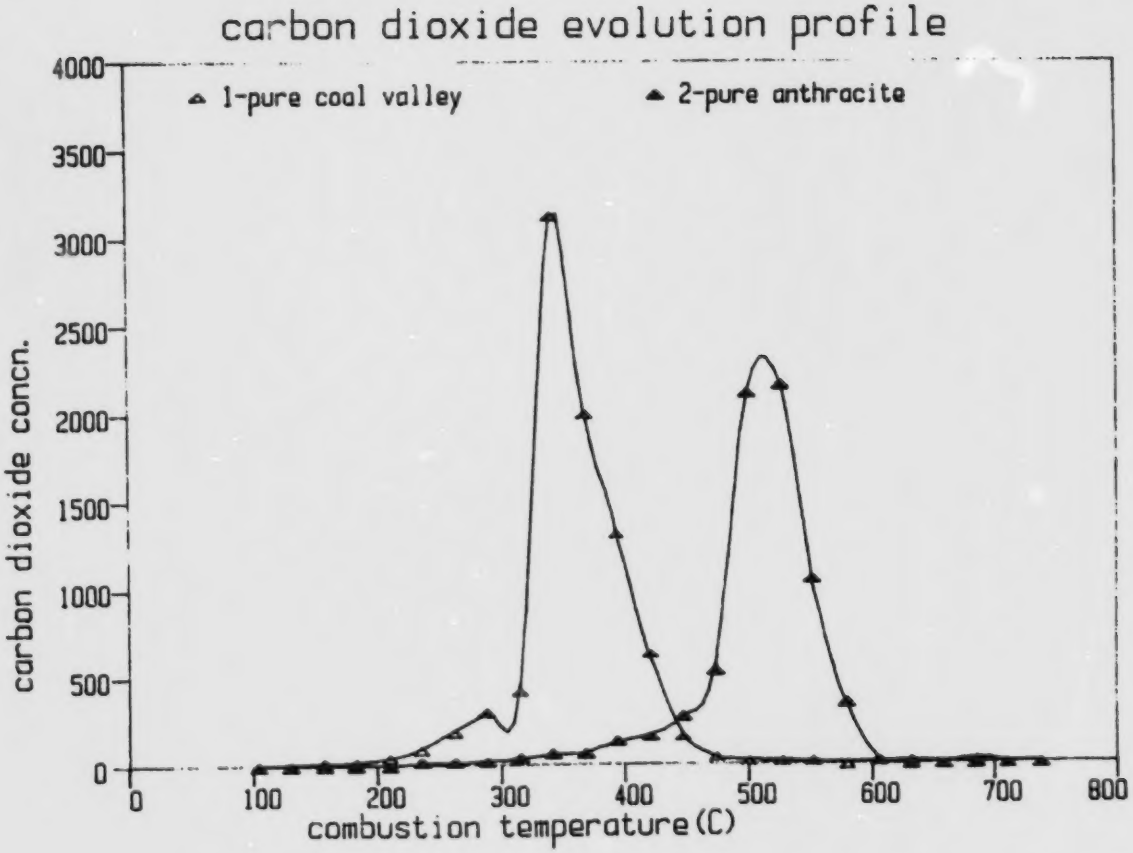

Effect of particle size on combustion temperature
conventional grind...A1
micronized grind...A2
Temperature(C)
600
590
580
570
560
550
540
530
520
510
500
0
25
50
75
100
%Combustion(dry-ash free)

FIGURE 12


carbon dioxide evolution profile
1-pure coal valley
2-pure anthracite
carbon dioxide concn.
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)

APPENDIX 1

STATEMENT OF WORK FOR

D.S.S. CONTRACT OSQ85-00076

"EVALUATION OF COMBUSTION OPTIONS FOR ANTHRACITE UTILIZATION"

Supply and Services Canada / Approvisionnements et Services Canada

11 LAURIER ST., HULL, QUEBEC K1A 0S5
11, RUE LAURIER, HULL (QUÉBEC) K1A 0S5

Gulf Canada Ltd.
Research & Development Department
2489 Sheridan Way
Sheridan Park, Ontario
L5K 1A8

31E52

4:4

P.I. – I.P. | PAGE 1 | OF PAGES 9

DSS FILE NUMBER – NUMÉRO DU DOSSIER MAS: 06SQ.23440-5-9078

ADDRESS ENQUIRIES TO – ADRESSER LES DEMANDES DE RENSEIGNEMENTS À: Dr. R.G. Agarwal (06SQ)

TEL.: (819/613) 997-7420

LOC: EEEE

CONTRACT - CONTRAT

YOU ARE REQUESTED — to sell and/or supply to Her Majesty the Queen in right of Canada upon the terms and conditions set out herein and on the reverse side hereof, the supplies and/or services listed below and any attached sheets at the price(s) set out therefor.

NOUS VOUS DEMANDONS — de vendre et/ou de fournir à Sa Majesté la Reine du chef du Canada, aux conditions énoncées au recto et au verso de la présente et au(x) prix indiqué(s) les articles et/ou les services énumérés ci-dessous et sur toute feuille ci-annexée.

F.o.b. POINT / POINT DE F. à. b.: OTTAWA, Ontario

CONSIGNEE / CONSIGNATAIRE: Energy, Mines and Resources
CANMET - Energy Research Laboratories
555 Booth Street
Ottawa, Ontario K1A 0G1

CODE 23440 Attention: J.R. Merry

INSPECTION: ☒ Destination ☐ Origin ☐ DND/SAD

PURCHASING AUTHORITY – MINISTÈRE DEMANDEUR: Energy, Mines & Resources 23

ITEM NO. / N° DE L'ARTICLE	DESCRIPTION	UNIT / UNITÉ	QUANTITY / QUANTITÉ	UNIT PRICE / PRIX UNITAIRE
	Z-0001-M-R-D			

PLEASE SIGN AND RETURN THIS COPY IMMEDIATELY TO

VEUILLEZ SIGNER ET RENVOYER CET EXEMPLAIRE IMMÉDIATEMENT AU

TITLE

EVALUATION OF CONVERSION OPTIONS FOR ANTHRACITE UTILIZATION
(50/50 Cost Shared Energy Conversion Program)

STATEMENT OF WORK

You shall perform the work as detailed in Appendix "A" attached hereto and forming part of this contract.

CONSIGNEE / CONSIGNATAIRE	VALUE – VALEUR	CONSIGNEE / CONSIGNATAIRE	VALUE – VALEUR	COUNTRY OF P.C. / ORIGINE Y.d.d.	VALUE OF FOREIGN CONTENT / VALEUR ÉLÉMENTS ÉTRANGERS
CONSIGNEE / CONSIGNATAIRE	VALUE – VALEUR	CONSIGNEE / CONSIGNATAIRE	VALUE – VALEUR	CDN	—

REVENUE SHARING – PARTAGE DES RECETTES

DELIVERY / LIVRAISON: March 31, 1986

TELEPHONE | DATE | FEDERAL SALES TAX / TAXE DE VENTE FÉDÉRALE: N/A

We hereby AGREE to sell and/or supply to Her Majesty the Queen in right of Canada, upon the terms and conditions set out herein and on the reverse side hereof, the supplies and/or services listed above and on any attached sheets at the price(s) set out therefor.

Nous CONSENTONS de vendre et/ou de fournir à Sa Majesté la Reine du chef du Canada, aux conditions énoncées au recto et au verso de la présente et au(x) prix indiqué(s) les articles et/ou les services énumérés ci-dessus et sur toute feuille ci-annexée.

PRINT NAME – NOM EN MAJUSCULES

SIGNATURE

DISCOUNT TERMS / CONDITIONS D'ESCOMPTE

INVOICES ARE TO BE MADE OUT TO – ÉTABLIR LES FACTURES AU NOM DE

Send the ORIGINAL and 2 COPIES to / Envoyer l'ORIGINAL et 2 copies au: Senior Science Procurement Officer named herein

☐ Send one copy to DSS / Envoyer un exemplaire au MAS: Scientific Authority

All invoices, shipping bills and packing slips must show the following numbers / Les factures, connaissements et bordereaux d'emballage doivent porter les numéros suivants:

DESCRIPTION AND FINANCIAL CODES – N° DE LA DEMANDE ET CODES FINANCIERS
RN: 23440-5-9078
FC: 234-131-000000-505702-0415

CONTRACT SERIAL NUMBER / NUMÉRO DE SÉRIE DU CONTRAT: 0SQ85-00076

CONTRACT – FACTURE: 06/06 /10 $24,710.00

EST. EXPENDITURE – MONTANT EST.: $24,710.00

DATE: JUN JUIN 12 1985

VENDOR – FOURNISSEUR: L5K

FOR THE DEPARTMENT – POUR LE MINISTÈRE

SIGNATURE

DEMAND THIS COPY

APPENDIX "A"

STATEMENT OF WORK

TITLE: EVALUATION OF COMBUSTION OPTIONS FOR ANTHRACITE UTILIZATION

Task 1: Acquisition, Preparation & Analysis of Mt. Klappan Anthracite

The proposed coal preparation facility for Mt. Klappan anthracite will generate a slate of products for various markets. Based on a 25% ash-content raw coal, products with about 5%, 10% and 20% ash contents, in addition to the coal reject, will be obtained.

The 10% ash clean coal is probably the most desirable product for export markets, for both coal producers and utility operators. Therefore, the 10% ash clean coal is recommended for this research program.

This task covers the work required to obtain a representative coal sample, (ca. 1 Kg), to analyze the 10% ash clean coal, and then prepare all the samples to appropriate size consist.

The 10% ash clean coal will be analyzed by a subcontracting laboratory for proximate and ultimate analyses, mineral analysis of ash, maceral analysis, calorific value and Hardgrove Grindability index. All the samples will also be prepared to a conventional grind and a micronized grind for this research proposal.

Task 2: Acquisition & Analysis of Reference Bituminous Thermal Coal

Bituminous thermal coals currently exported to offshore markets from Canadian operations, will be used for coal mixture studies, and as reference samples, for this research program.

Coal Valley clean coal (CV) and Obed Marsh clean coal (OM) will be used for this research program. About 1 Kg of each will be obtained by Gulf and shipped to a testing laboratory.

These clean coals will be analyzed for the same parameters as in Task 1, by the subcontractor laboratory. The samples will also be prepared to appropriate size consist as required.

2 of 2 pages
8106-S-0022-0591

Task 3: Combustion Behaviour of Anthracite/Thermal Coal Mixtures by Thermogravimetric Analysis

This task will investigate the possibility of burning anthracite/thermal coal mixtures using the size consist of conventional pulverized grind and micronized grind for the anthracite component. The conventional grind is defined as pulverized coal with 70% of 74 microns x 0, with a top size of 250 microns, whereas the micronized grind has 100% of 44 microns x 0. The method used here is thermogravimetric analysis (TGA), supported by analysis of gas evolved from TGA.

The general operating conditions of TGA will be 10C/minute temperature programming rate, 100 mL/min. of gas flow, and a temperature range from ambient to 1000C. Nitrogen will be used in determining volatile release profile and oxygen will be used in determining combustion profile. The coal mixtures prepared for this task will be subjected to proximate analysis to confirm that the mixtures are homogeneous.

Experimental work will be carried out using an Omnitherm 25TG950 thermogravimetric modul supervised by a DuPont 1090 Thermal Analyzer based system. The 1090 base unit performs modul programming and control as well as data acquisition and analysis using a DuPont 1091 dual disk memory unit.

A Carle Model 330 CGC will be physically interfaced to the TGA modul such that the gases evolved during a run were available to the GC for analysis. The GC will be programmed for cyclic analysis in such a manner as to allow sequential gas measurements to be produced throughout the duration of the TGA experimental run at 5 min. intervals.

The TGA data will be acquired and subsequently analyzed off-line on the DuPont 1090 TGA software. The gas profiles will be generated on an IBM PC under Energraphics by converting the GC sampling times to TGA run temperatures using a temperature vs. time plot generated by the DuPont 1090.

The TGA data will be analyzed to establish ignition temperature, temperature of inflection and of complete combustion, and the temperatures at various levels of combustion. The gas composition data will be correlated with all these temperatures. An experimental program for this task is outlined in Table 1.

TABLE 1

EXPERIMENTAL PROGRAM FOR TASK 3

Coal Mixtures
Clean Anthracite = A (2 grinds)
Bituminous Coal 1 = CV (1 grind)
Bituminous Coal 2 = OM (1 grind)

A & CV Mixtures

	100% A	75% A	50% A	25% A	0% A
Volatile Release Profile					
Conventional Grind	X	X	X	X	X
Micronized Grind	X	X	X	X	
Combustion Profile					
Conventional Grind	X	X	X	X	X
Micronized Grind	X	X	X	X	

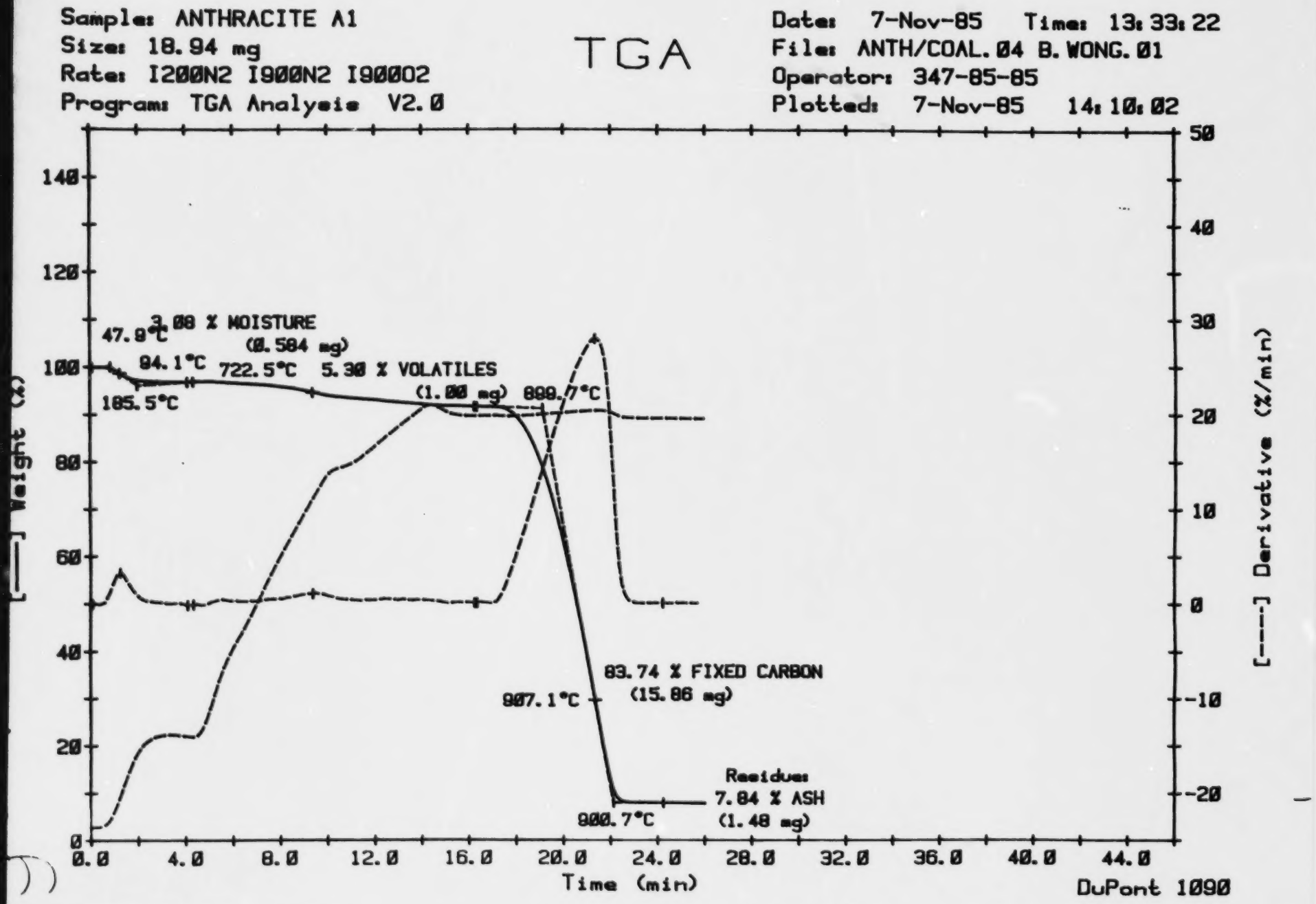
A & OM Mixtures

Combustion Profile					
Conventional Grind		X	X	X	X
Micronized Grind		X	X	X	

APPENDIX 2

PROXIMATE ANALYSIS OF COAL SAMPLES

BY THERMOGRAVIMETRIC ANALYSIS (TGA)

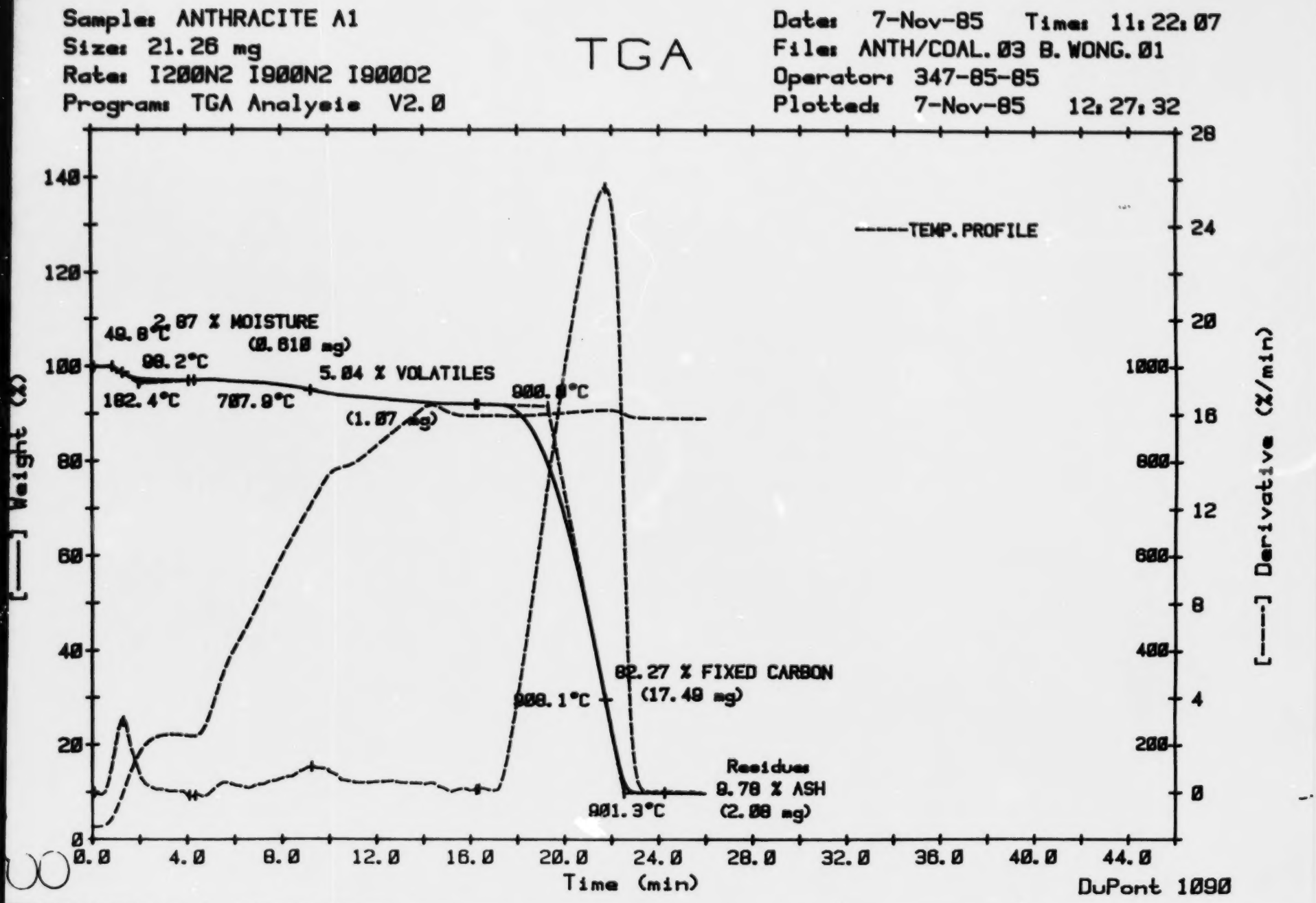

Sample: ANTHRACITE A1
Size: 18.94 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 7-Nov-85 Time: 13:33:22
File: ANTH/COAL.04 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 14:10:02
47.9°C
3.08 % MOISTURE
(0.584 mg)
94.1°C
722.5°C 5.30 % VOLATILES
(1.00 mg)
889.7°C
185.5°C
83.74 % FIXED CARBON
(15.86 mg)
907.1°C
Residue:
7.84 % ASH
(1.48 mg)
900.7°C
[——] Weight (%)
[----] Derivative (%/min)
Time (min)
DuPont 1090

Sample: ANTHRACITE A1
Size: 18.94 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 7-Nov-85 Time: 13:33:22
File: ANTH/COAL.04 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 14:31:56

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	47.9	94.1	185.5	0.58	3.08
VOLATILES		722.5		1.00	5.30
FIXED CARBON	899.7	907.1	900.7	15.86	83.74
ASH	Residue at 889.9 °C			1.48	7.84

Modified Sample Weight: 18.93 mg

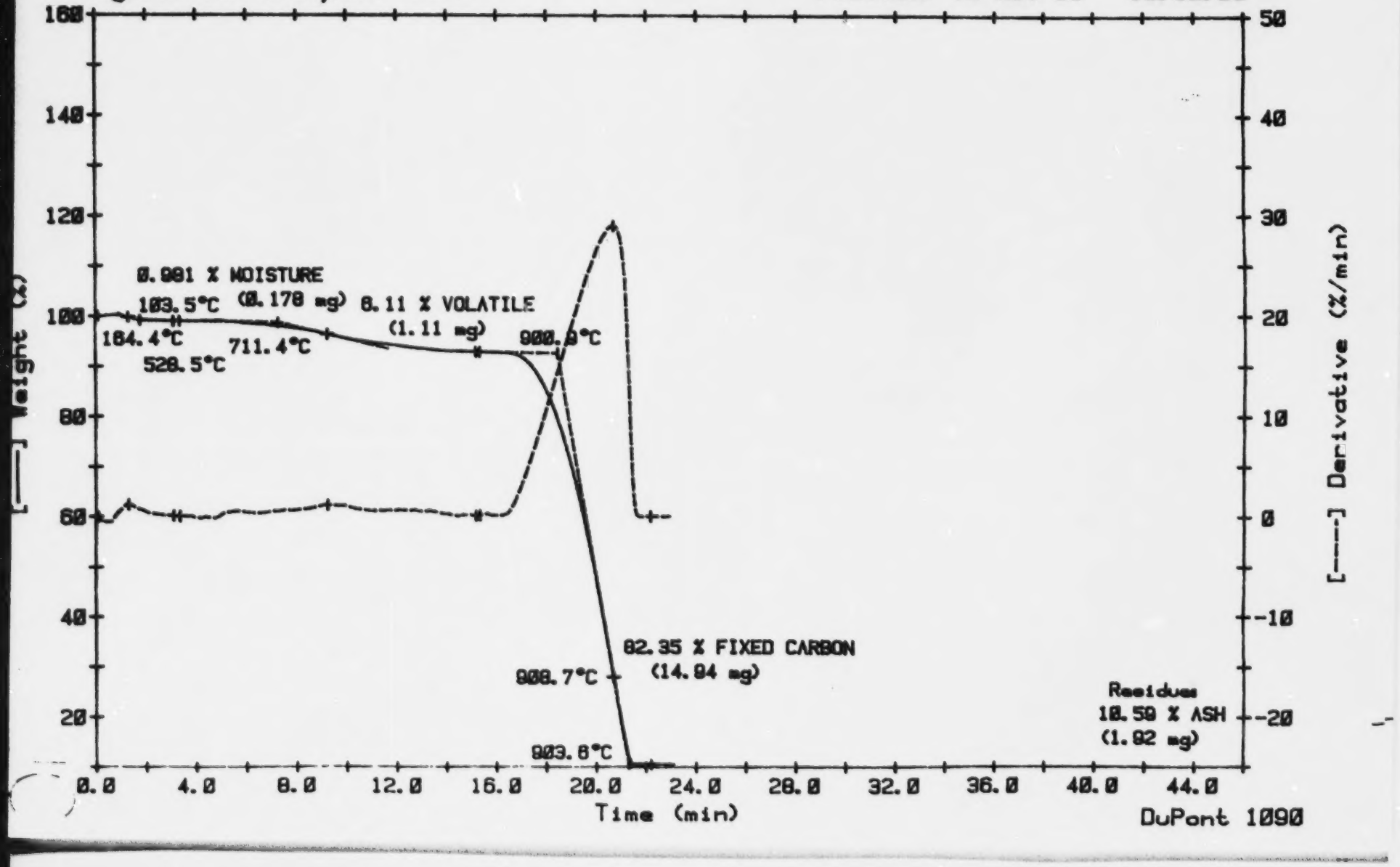

Sample: ANTHRACITE A1
Size: 21.26 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 7-Nov-85 Time: 11:22:07
File: ANTH/COAL.03 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 12:27:32
-----TEMP.PROFILE
2.87 % MOISTURE
(0.610 mg)
49.8°C
98.2°C
5.84 % VOLATILES
182.4°C
707.9°C
900.0°C
(1.87 mg)
82.27 % FIXED CARBON
(17.49 mg)
908.1°C
Residue
9.78 % ASH
(2.08 mg)
901.3°C
[——] Weight (%)
[----] Derivative (%/min)
Time (min)
DuPont 1090

Sample: ANTHRACITE A1
Size: 21.26 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 7-Nov-85 Time: 11:22:07
File: ANTH/COAL.03 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 13:40:48

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	49.8	98.2	182.4	0.61	2.87
VOLATILES		707.9		1.07	5.04
FIXED CARBON	900.0	908.1	901.3	17.49	82.27
ASH	Residue at 890.2 °C			2.08	9.78

Modified Sample Weight: 21.26 mg

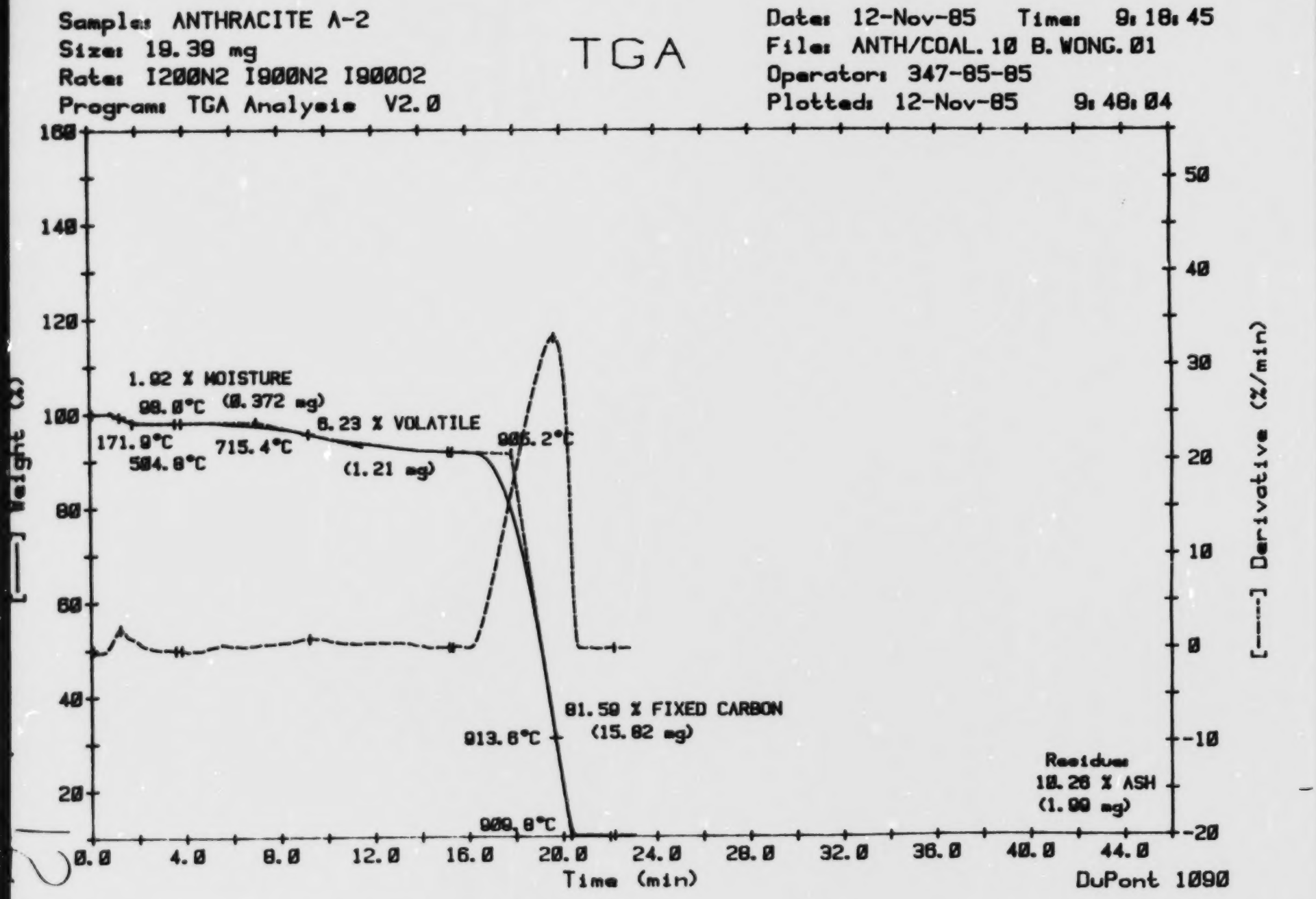

Sample: ANTHRACITE A-2
Size: 18.14 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 11-Nov-85 Time: 15:04:27
File: ANTH/COAL.09 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 15:32:06
0.981 % MOISTURE
103.5°C (0.178 mg)
6.11 % VOLATILE
(1.11 mg)
184.4°C
711.4°C
528.5°C
900.9°C
82.35 % FIXED CARBON
(14.94 mg)
908.7°C
903.8°C
Residue
10.59 % ASH
(1.92 mg)
[—] Weight (%)
[----] Derivative (%/min)
Time (min)
DuPont 1090

Sample: ANTHRACITE A-2
Size: 18.14 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 11-Nov-85 Time: 15:04:27
File: ANTH/COAL.09 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 15:42:15

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		103.5	164.4	0.18	0.98
VOLATILE	528.5	711.4		1.11	6.11
FIXED CARBON	900.9	908.7	903.6	14.94	82.35
ASH	Residue at 892.2 °C			1.92	10.59

Modified Sample Weight: 18.14 mg

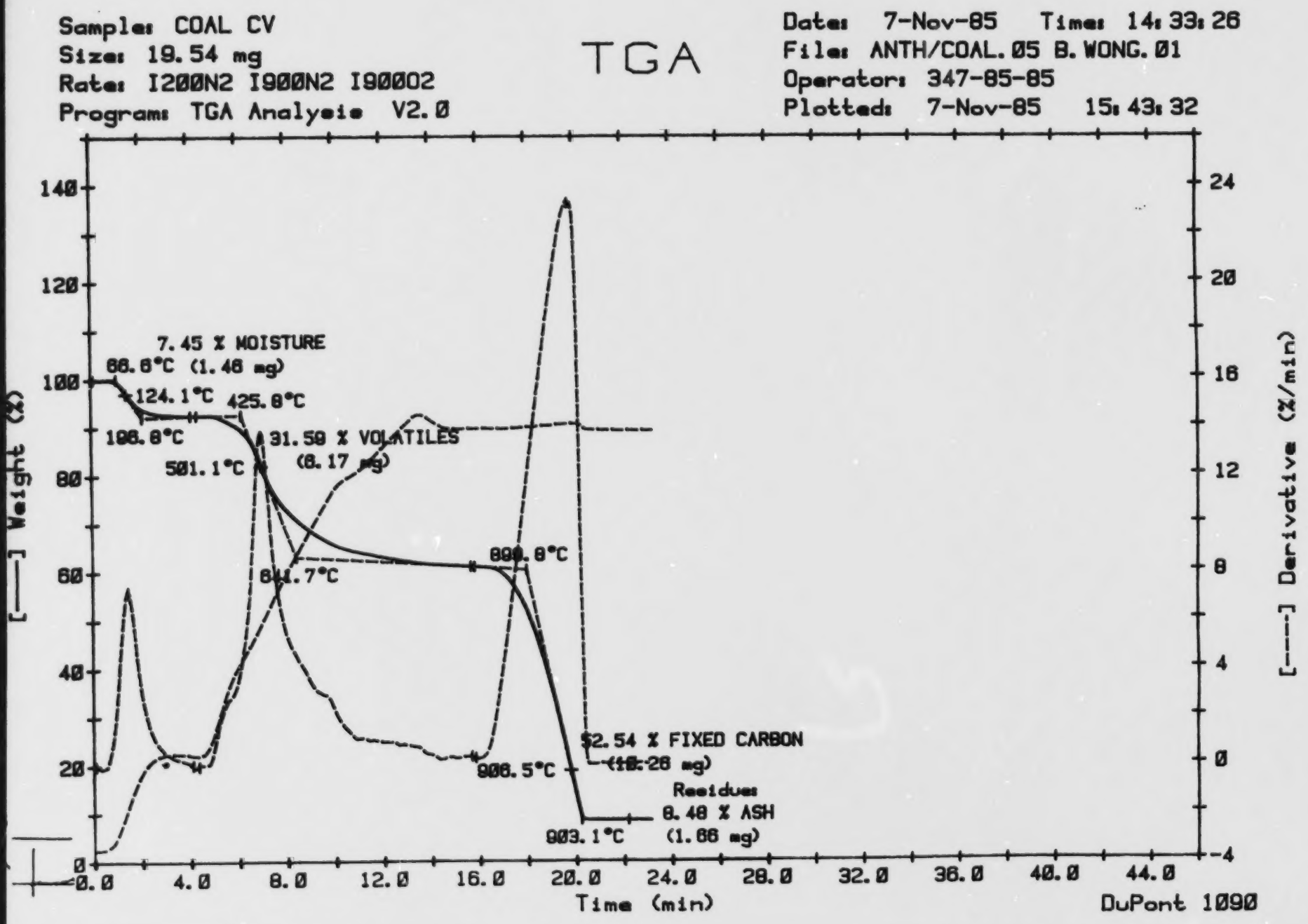

Sample: ANTHRACITE A-2
Size: 19.39 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 12-Nov-85 Time: 9:18:45
File: ANTH/COAL.10 B.WONG.01
Operator: 347-85-85
Plotted: 12-Nov-85 9:48:04
1.92 % MOISTURE
98.0°C (0.372 mg)
6.23 % VOLATILE
171.9°C
584.8°C
715.4°C
(1.21 mg)
905.2°C
913.6°C
81.59 % FIXED CARBON
(15.82 mg)
909.8°C
Residue
10.26 % ASH
(1.99 mg)
[——] Weight (%)
[----] Derivative (%/min)
Time (min)
DuPont 1090

Sample: ANTHRACITE A-2
Size: 19.39 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 12-Nov-85 Time: 9:18:45
File: ANTH/COAL.10 B.WONG.01
Operator: 347-85-85
Plotted: 12-Nov-85 9:55:19

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		98.0	171.9	0.37	1.92
VOLATILE	504.8	715.4		1.21	6.23
FIXED CARBON	905.2	913.6	909.8	15.82	81.59
ASH	Residue at 895.4 °C			1.99	10.26

Modified Sample Weight: 19.39 mg


Sample: COAL CV
Size: 19.54 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 7-Nov-85 Time: 14:33:26
File: ANTH/COAL.05 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 15:43:32
7.45 % MOISTURE
66.6°C (1.46 mg)
124.1°C
425.8°C
198.8°C
31.59 % VOLATILES
(6.17 mg)
501.1°C
611.7°C
890.8°C
52.54 % FIXED CARBON
(10.26 mg)
906.5°C
Residue
8.48 % ASH
(1.66 mg)
903.1°C
[---] Weight (%)
[---] Derivative (%/min)
Time (min)
DuPont 1090

Sample: COAL CV
Size: 19.54 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 7-Nov-85 Time: 14:33:26
File: ANTH/COAL.05 B.WONG.01
Operator: 347-85-85
Plotted: 7-Nov-85 15:51:40

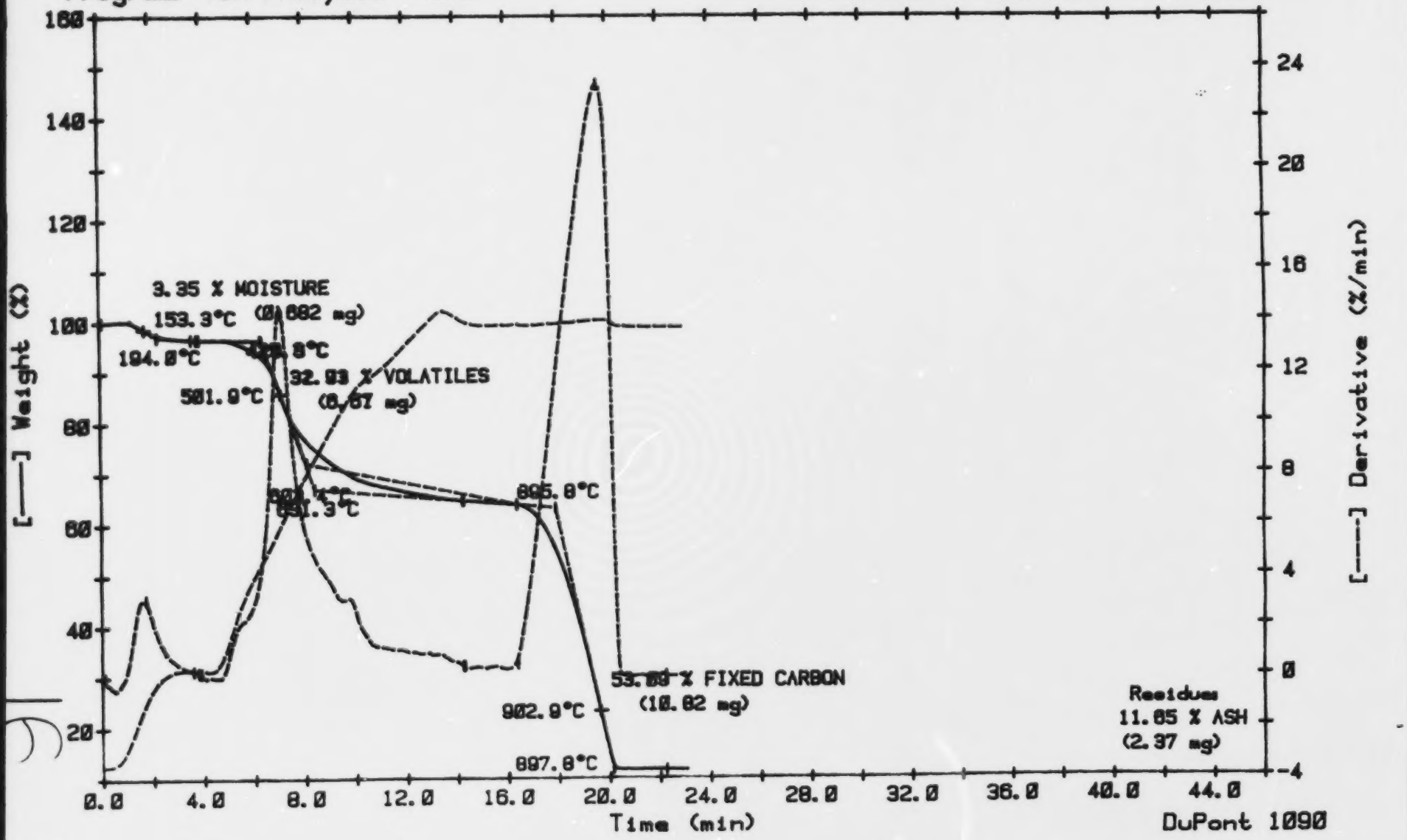
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	66.6	124.1	196.8	1.46	7.45
VOLATILES	425.8	501.1	641.7	6.17	31.59
FIXED CARBON	899.8	906.5	903.1	10.26	52.54
ASH	Residue at 891.9 °C			1.66	8.48

Modified Sample Weight: 19.54 mg

Sample: COAL CV
Size: 20.38 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

TGA

Date: 11-Nov-85 Time: 8:37:46
File: ANTH/COAL.06 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 9:39:16



Sample: COAL CV
Size: 20.38 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 11-Nov-85 Time: 8:37:46
File: ANTH/COAL.06 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 9:55:39

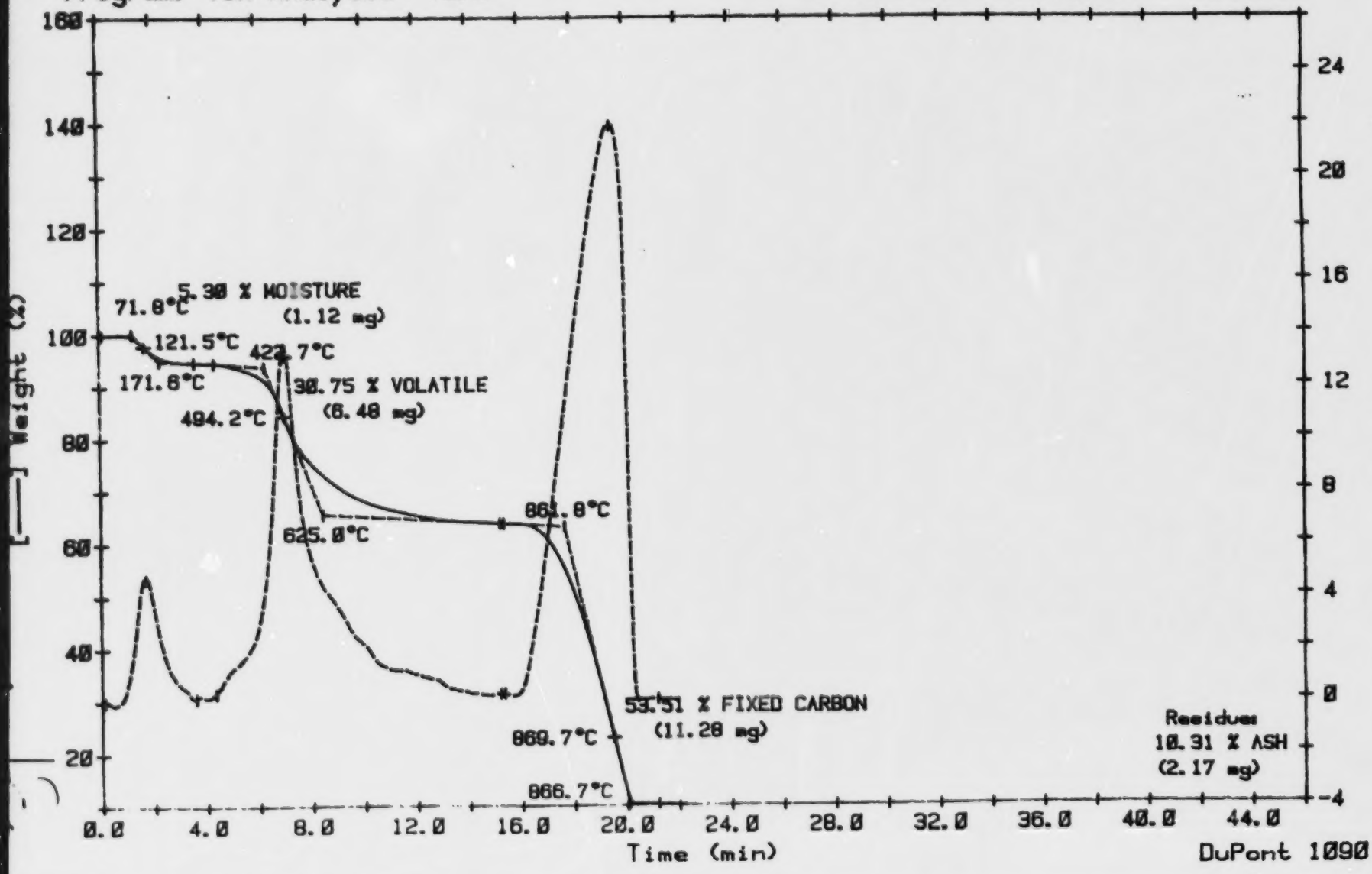
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		153.3	194.0	0.68	3.35
VOLATILES	429.6	501.9	631.3	6.51	31.93
FIXED CARBON	895.8	902.9	897.8	10.82	53.09
ASH	Residue at 887.8 °C			2.37	11.65

Modified Sample Weight: 20.38 mg

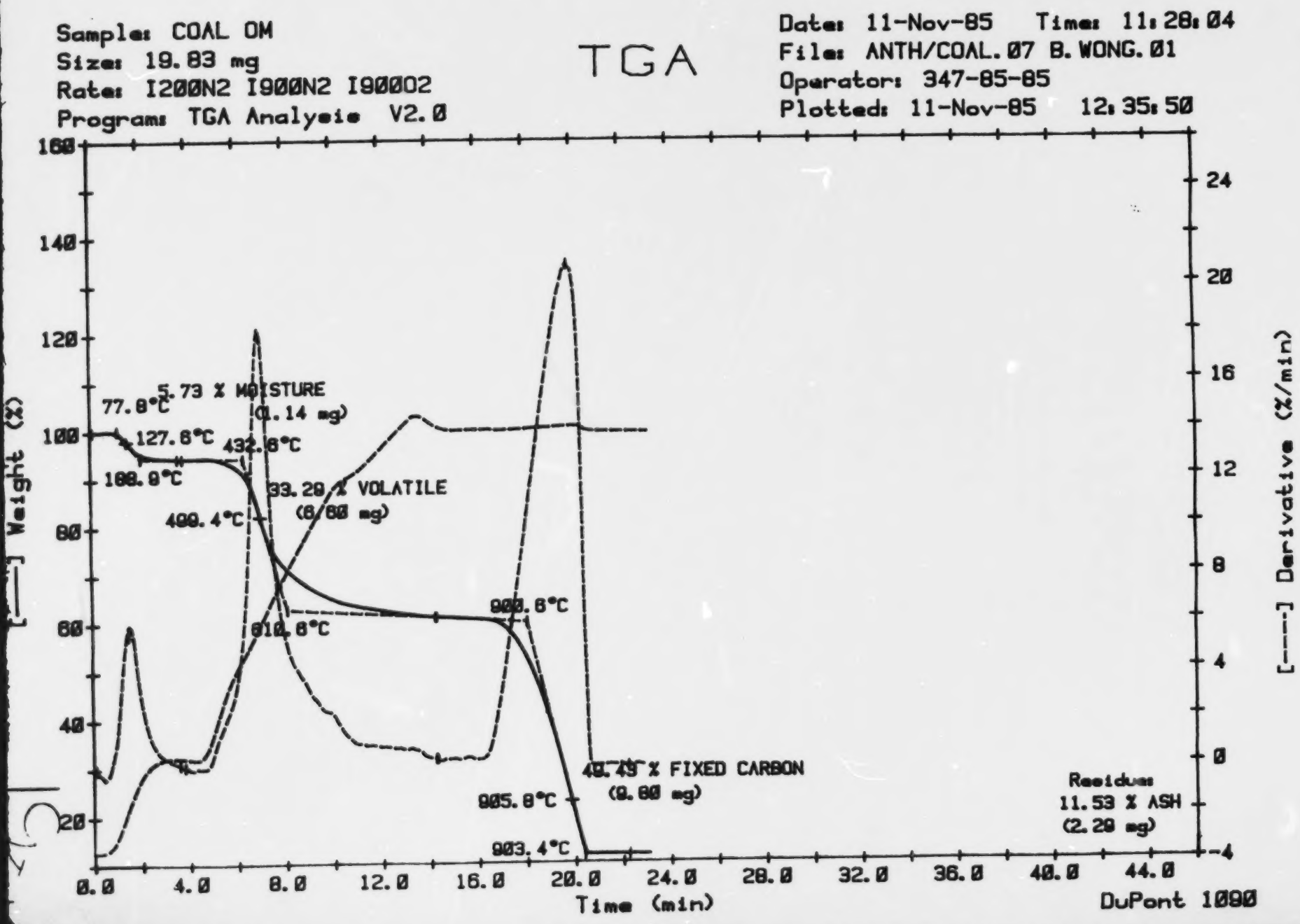
Sample: COAL CV
Size: 21.09 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

TGA

Date: 12-Nov-85 Time: 17:16:55
File: ANTH/COAL.13 B.WONG.01
Operator: 347-85-85
Plotted: 13-Nov-85 7:36:10



DuPont 1090


Sample: COAL OM
Size: 19.83 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 11-Nov-85 Time: 11:28:04
File: ANTH/COAL.07 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 12:35:50
77.8°C
5.73 % MOISTURE
(1.14 mg)
127.6°C
432.6°C
188.8°C
33.28 % VOLATILE
(6.60 mg)
499.4°C
900.6°C
810.6°C
49.49 % FIXED CARBON
(9.80 mg)
905.8°C
903.4°C
Residue:
11.53 % ASH
(2.29 mg)
[——] Weight (%)
[----] Derivative (%/min)
Time (min)
DuPont 1090

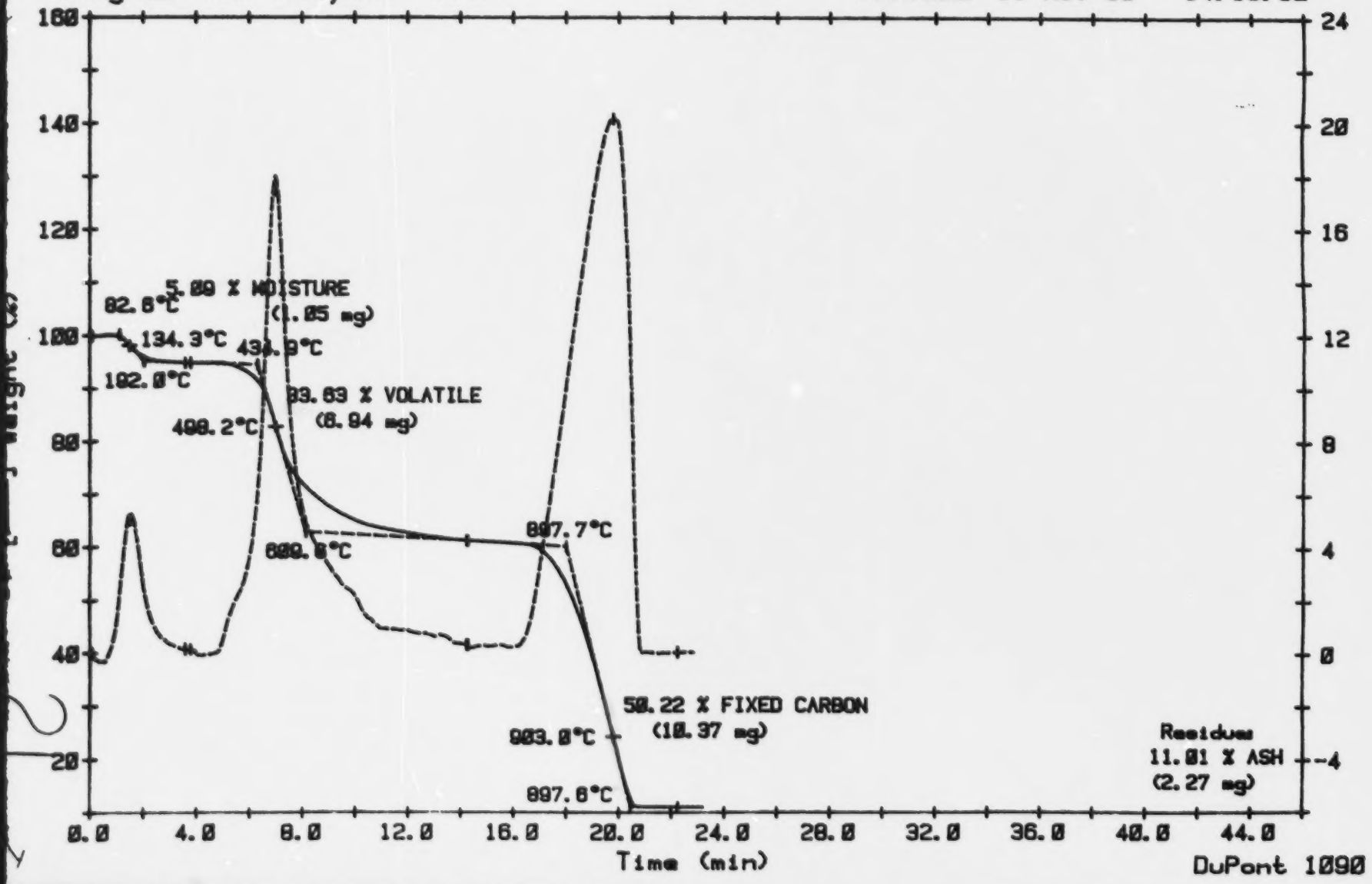
Sample: COAL OM
Size: 19.83 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0

Date: 11-Nov-85 Time: 11:28:04
File: ANTH/COAL.07 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 13:07:04

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	77.8	127.6	188.9	1.14	5.73
VOLATILE	432.6	499.4	610.6	6.60	33.29
FIXED CARBON	900.6	905.8	903.4	9.80	49.43
ASH	Residue at 893.2 °C			2.29	11.53

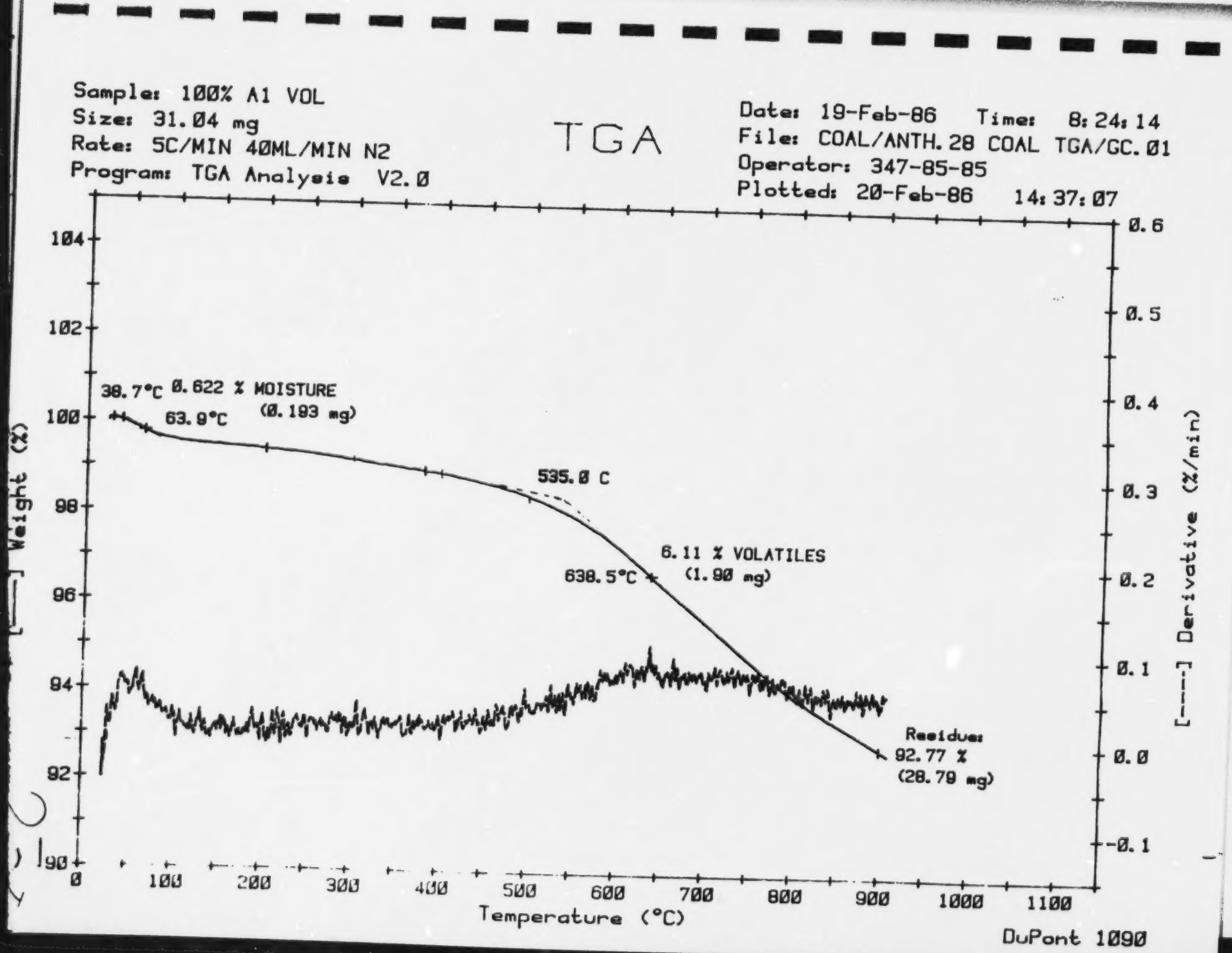
Modified Sample Weight: 19.83 mg

12


Sample: COAL OM
Size: 20.65 mg
Rate: I200N2 I900N2 I90002
Program: TGA Analysis V2.0
TGA
Date: 11-Nov-85 Time: 13:36:29
File: ANTH/COAL.08 B.WONG.01
Operator: 347-85-85
Plotted: 11-Nov-85 14:18:52
5.09 % MOISTURE
(1.05 mg)
82.6°C
134.3°C
192.8°C
438.9°C
83.69 % VOLATILE
(8.94 mg)
498.2°C
889.8°C
897.7°C
58.22 % FIXED CARBON
(12.37 mg)
903.8°C
897.6°C
Residue
11.01 % ASH
(2.27 mg)
Time (min)
[----] Derivative (%/min)
DuPont 1090

APPENDIX 3

VOLATILE RELEASE PROFILES FOR COAL SAMPLES


Sample: 100% A1 VOL
Size: 31.04 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0
TGA
Date: 19-Feb-86 Time: 8:24:14
File: COAL/ANTH.28 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 14:37:07
38.7°C 0.622 % MOISTURE
63.9°C (0.193 mg)
535.0 C
6.11 % VOLATILES
638.5°C (1.90 mg)
Residue:
92.77 %
(28.79 mg)
[___] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
DuPont 1090

Sample: 100% A2 VOL
Size: 28.41 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0

Date: 19-Feb-86 Time: 13:23:54
File: COAL/ANTH.29 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 15:33:36

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		49.7		0.23	0.80
VOLATILES	540.0	643.0		2.01	7.07
	Residue at 952.2 °C			25.74	90.62

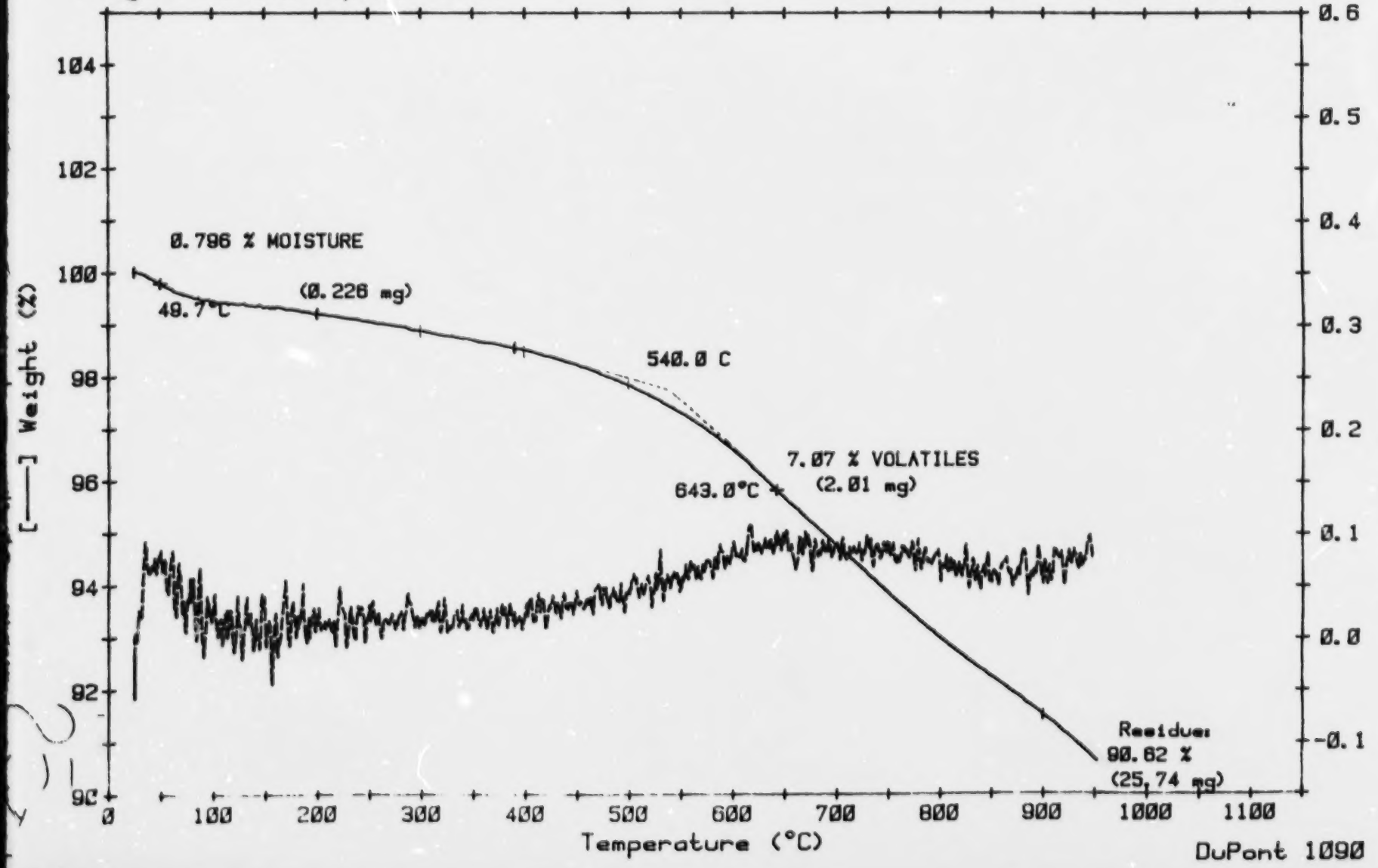
Modified Sample Weight: 28.40 mg

F2

Sample: 100% A2 VOL
Size: 28.41 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0

TGA

Date: 19-Feb-86 Time: 13:23:54
File: COAL/ANTH.29 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 15:07:58



DuPont 1090

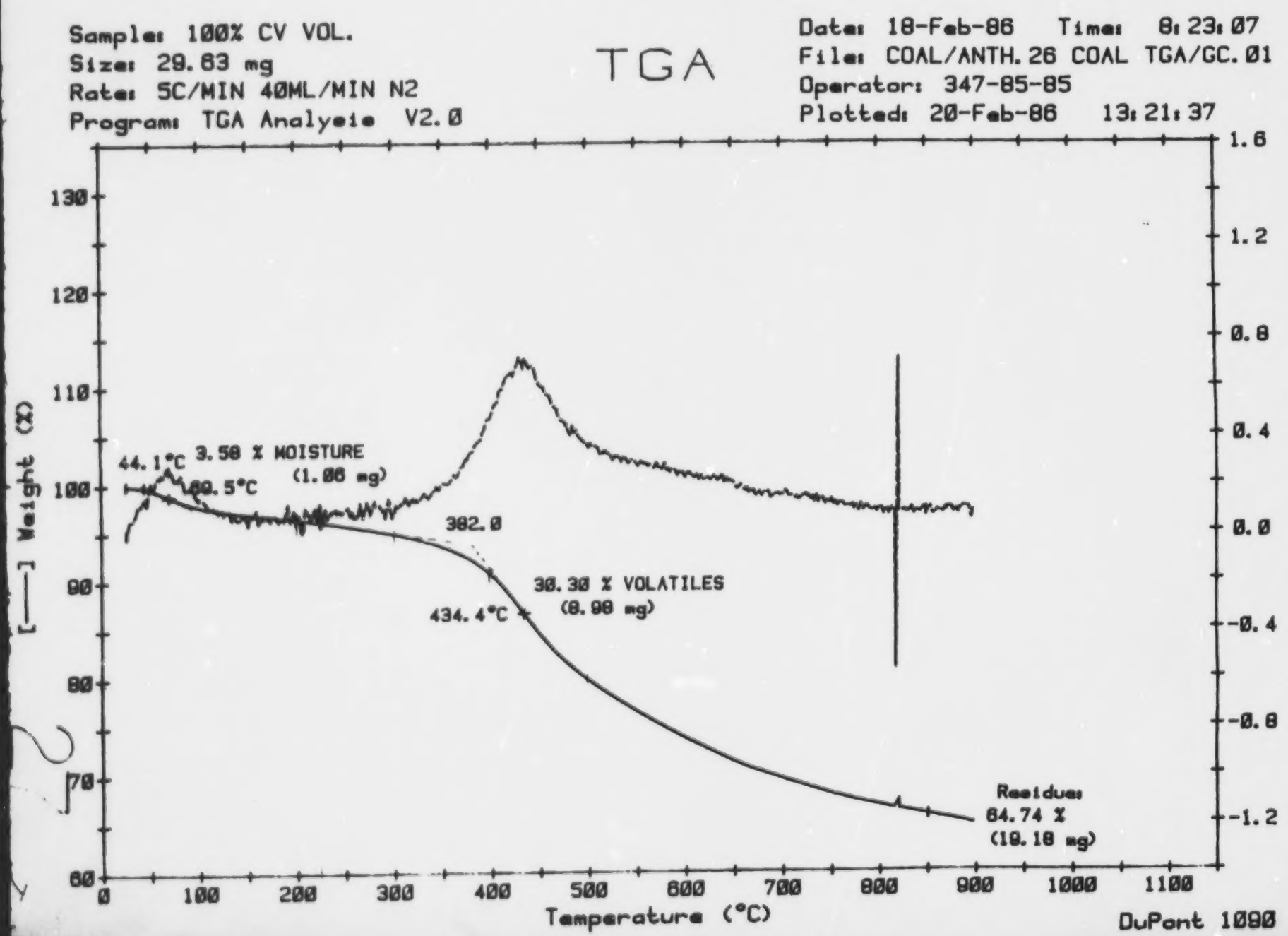
Sample: 100% A2 VOL
Size: 28.41 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0

Date: 19-Feb-86 Time: 13:23:54
File: COAL/ANTH.29 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 15:24:55

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		49.7		0.23	0.80
MOISTURE		49.7		0.23	0.80
VOLATILES		643.0		2.01	7.07
	Residue at 952.2 °C			25.74	90.62

Modified Sample Weight: 28.40 mg

N2


Sample: 100% CV VOL.
Size: 29.63 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0
TGA
Date: 18-Feb-86 Time: 8:23:07
File: COAL/ANTH.26 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 13:21:37
44.1°C
3.58 % MOISTURE
(1.06 mg)
89.5°C
382.0
30.30 % VOLATILES
(8.98 mg)
434.4°C
Residue:
64.74 %
(19.18 mg)
[——] Weight (%)
[- - -] Derivative (%/min)
Temperature (°C)
DuPont 1090

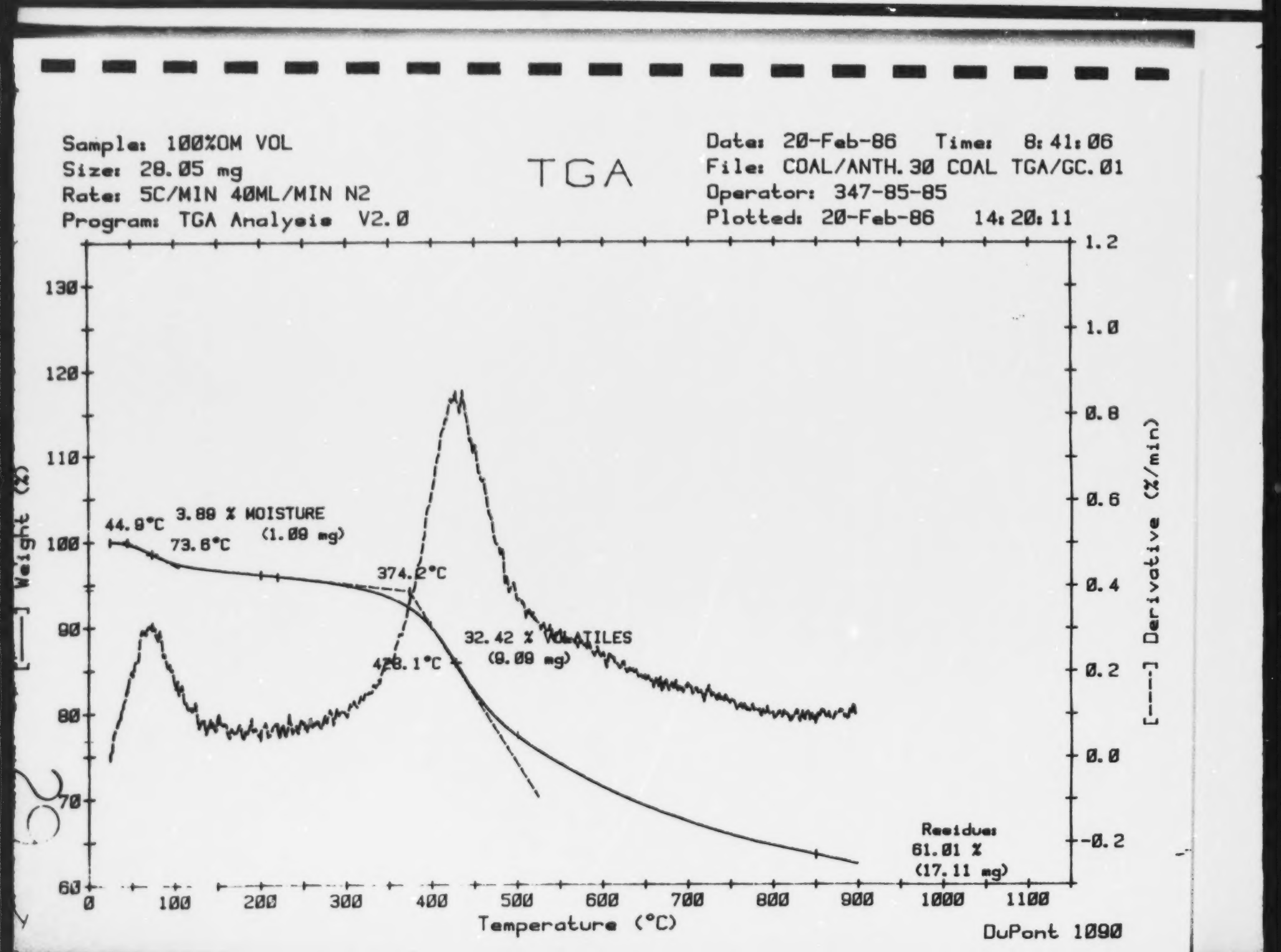
Sample: 100% CV VOL.
Size: 29.63 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0

Date: 18-Feb-86 Time: 8:23:07
File: COAL/ANTH.26 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 13:49:00

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	44.1	69.5		1.06	3.58
VOLATILES	382.0	434.4		8.98	30.30
	Residue at 901.2 °C			19.18	64.74

Modified Sample Weight: 29.63 mg

32


Sample: 100%OM VOL
Size: 28.05 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0
TGA
Date: 20-Feb-86 Time: 8:41:06
File: COAL/ANTH.30 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 14:20:11
[——] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
44.9°C
73.6°C
3.89 % MOISTURE
(1.09 mg)
374.2°C
428.1°C
32.42 % VOLATILES
(9.09 mg)
Residue:
61.01 %
(17.11 mg)
DuPont 1090

Sample: 100%OM VOL
Size: 28.05 mg
Rate: 5C/MIN 40ML/MIN N2
Program: TGA Analysis V2.0

Date: 20-Feb-86 Time: 8:41:06
File: COAL/ANTH.30 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 20-Feb-86 14:26:38

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	44.9	73.6		1.09	3.89
VOLATILES	374.2	428.1		9.09	32.42
		Residue at 953.3 °C		17.11	61.01

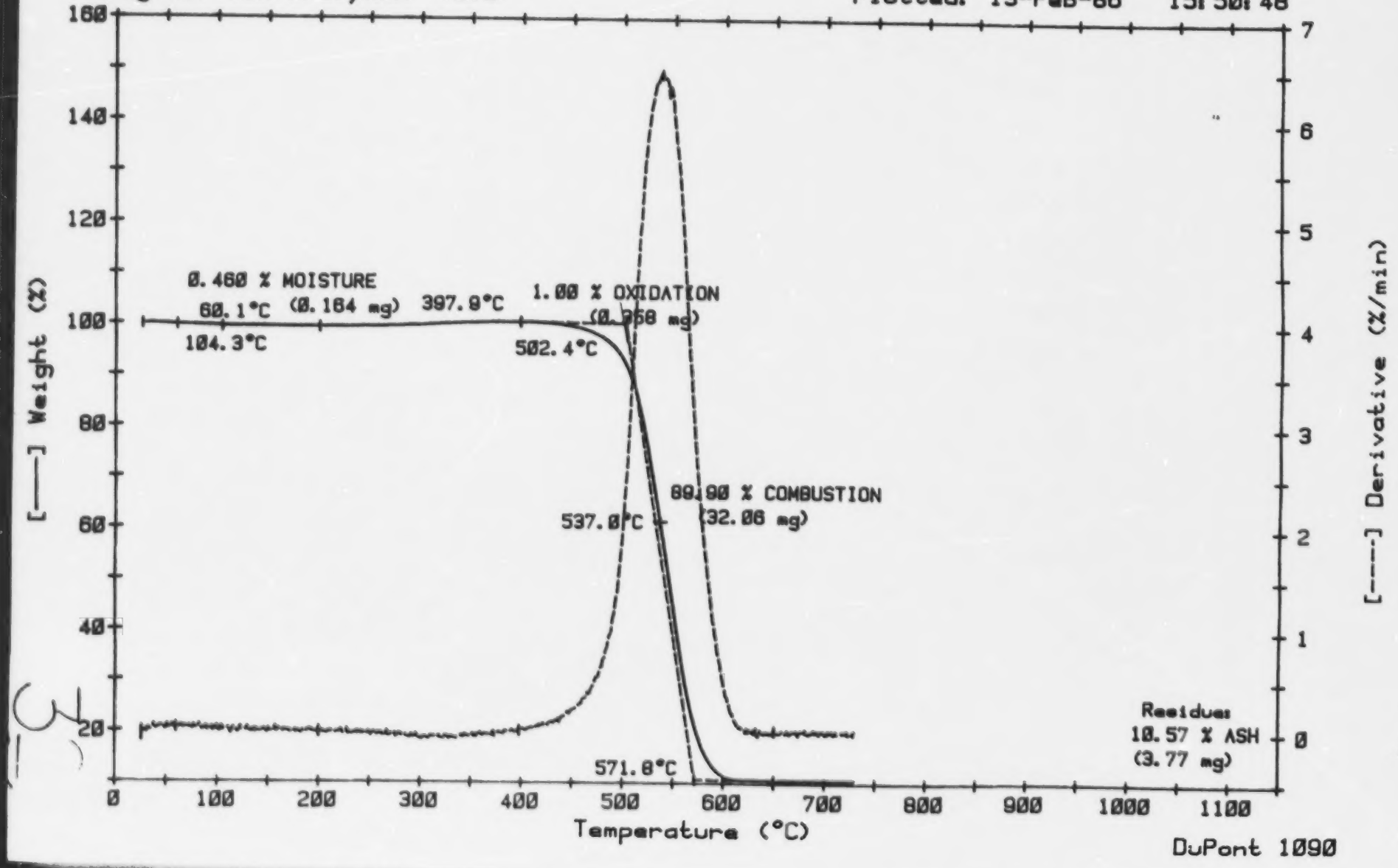
Modified Sample Weight: 28.04 mg

(N

APPENDIX 4

COMBUSTION PROFILES FOR COAL AND COAL MIXTURES

BY THERMOGRAVIMETRIC ANALYSIS (TGA)


Sample: 100% A1
Size: 35.66 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 29-Jan-86 Time: 12:26:40
File: COAL/ANTH.08 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 15:50:48
0.460 % MOISTURE
60.1°C (0.164 mg) 397.9°C
104.3°C
1.00 % OXIDATION
(0.358 mg)
502.4°C
89.90 % COMBUSTION
(32.06 mg)
537.0°C
571.8°C
Residue:
10.57 % ASH
(3.77 mg)
[——] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
DuPont 1090

Sample: 100% A1
Size: 35.66 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 29-Jan-86 Time: 12:26:40
File: COAL/ANTH.08 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 15:58:48

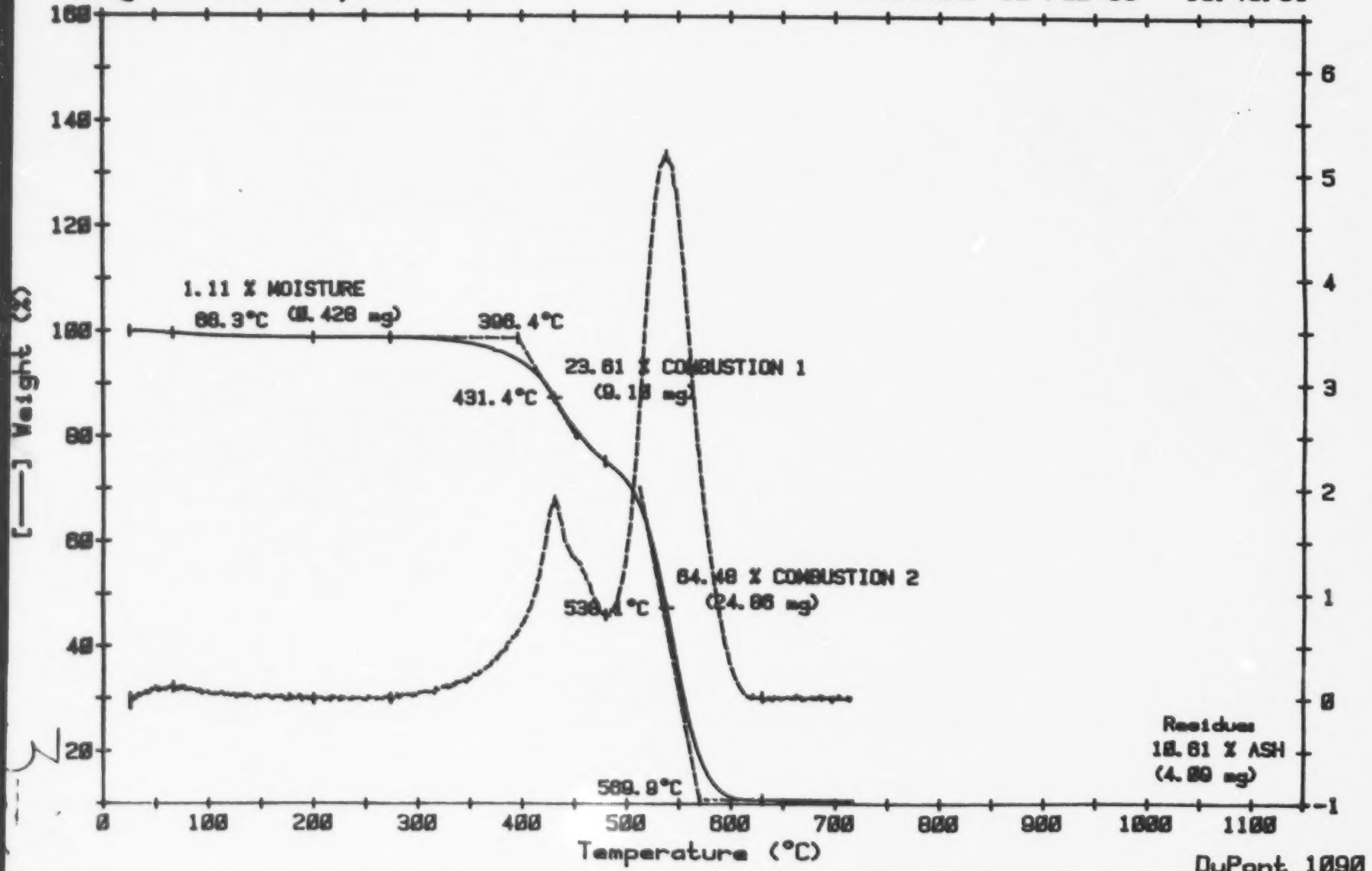
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		60.1	104.3	0.16	0.46
OXIDATION		397.9		0.36	1.00
COMBUSTION	502.4	537.0	571.8	32.06	89.90
ASH	Residue at 730.6 °C			3.77	10.57

Modified Sample Weight: 35.66 mg

Sample: 25%CV 75%A1
Size: 38.56 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 29-Jan-86 Time: 8:33:52
File: COAL/ANTH.07 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 15:46:31



DuPont 1090

Sample: 25%CV 75%A1
Size: 38.56 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

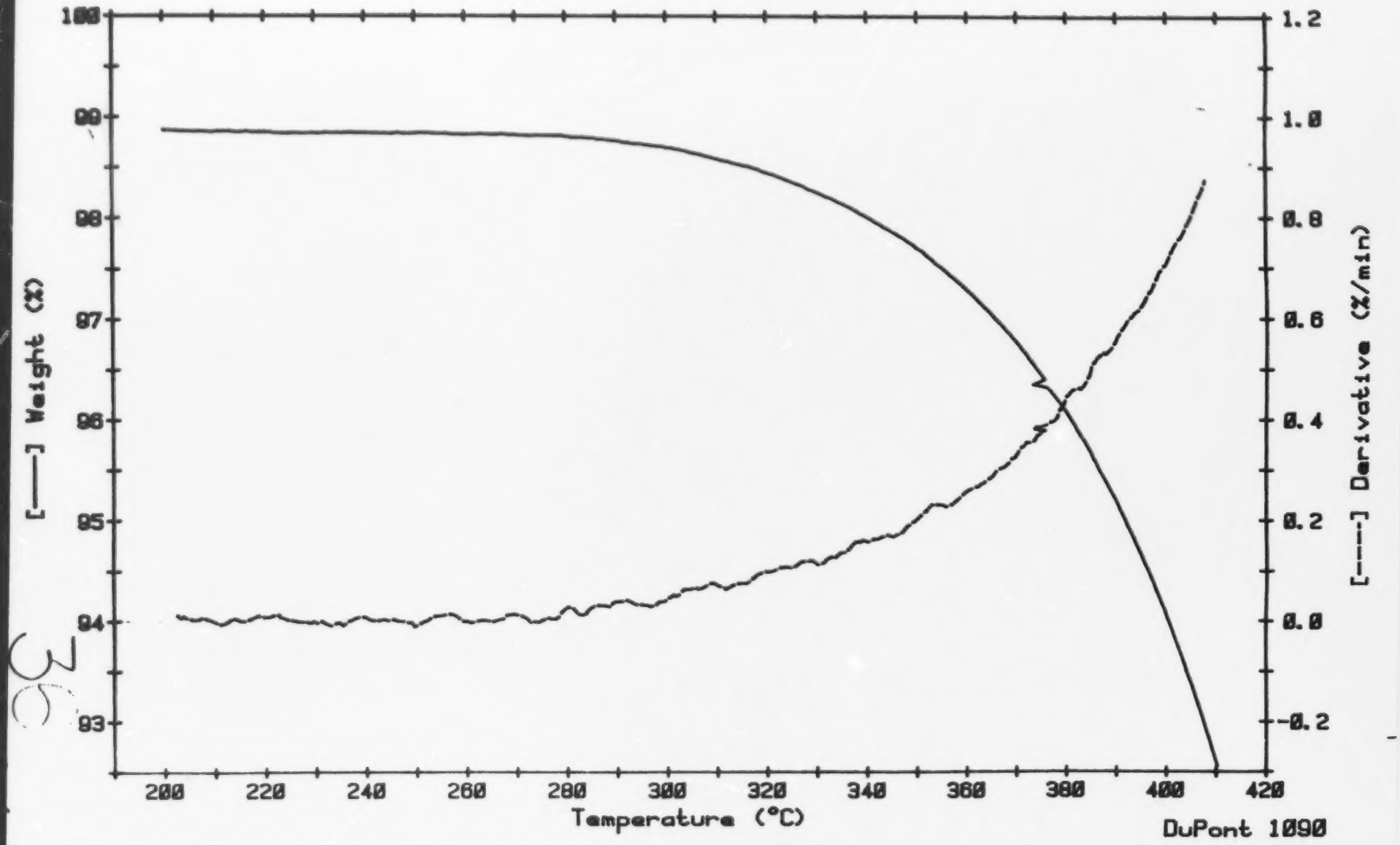
Date: 29-Jan-86 Time: 8:33:52
File: COAL/ANTH.07 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 15:57:26

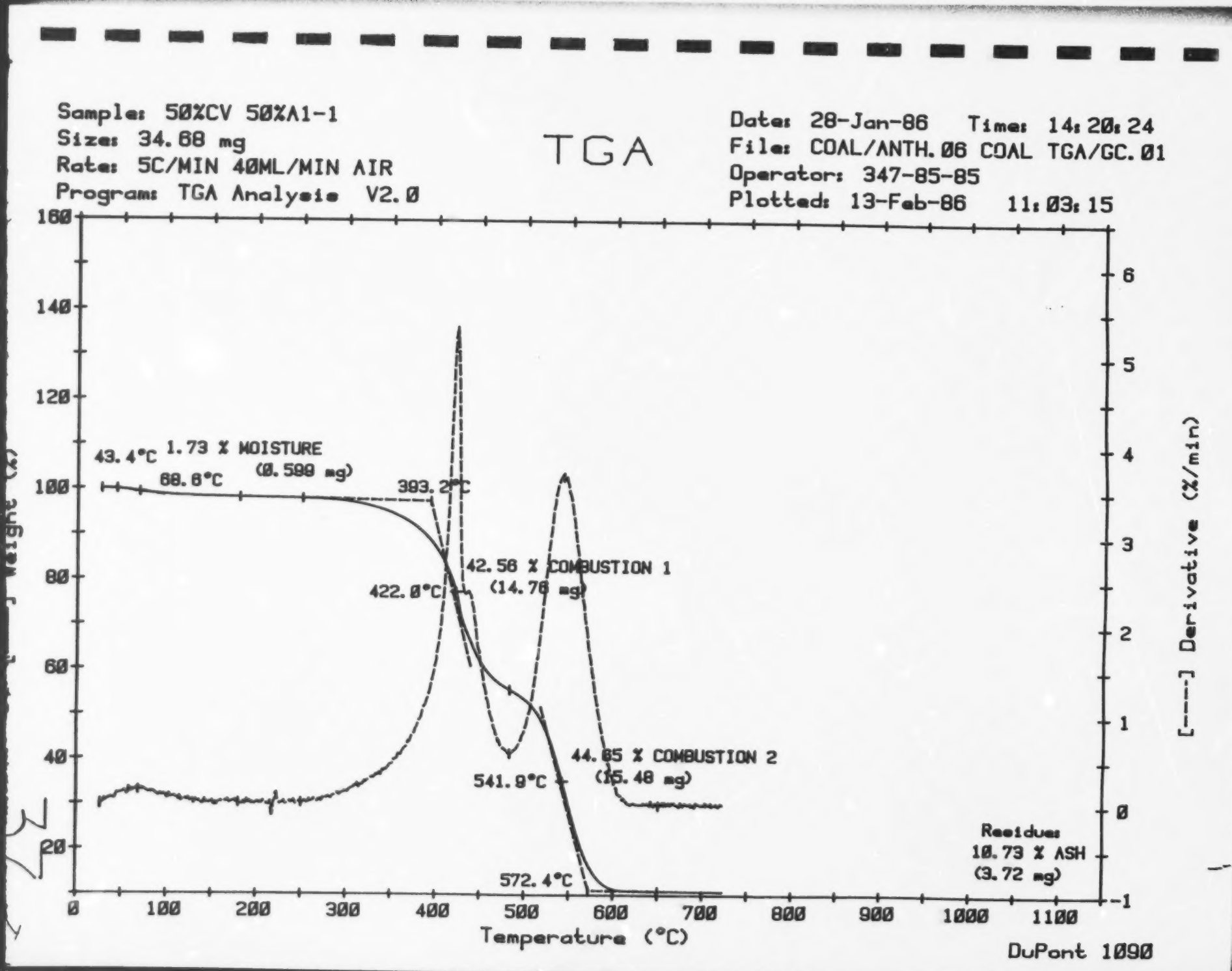
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		66.3		0.43	1.11
COMBUSTION 1	396.4	431.4		9.10	23.61
COMBUSTION 2		538.1	569.9	24.86	64.48
ASH	Residue at 720.4 °C			4.09	10.61

Modified Sample Weight: 38.56 mg

Sample: 25%CV 75%A1
Size:

TGA



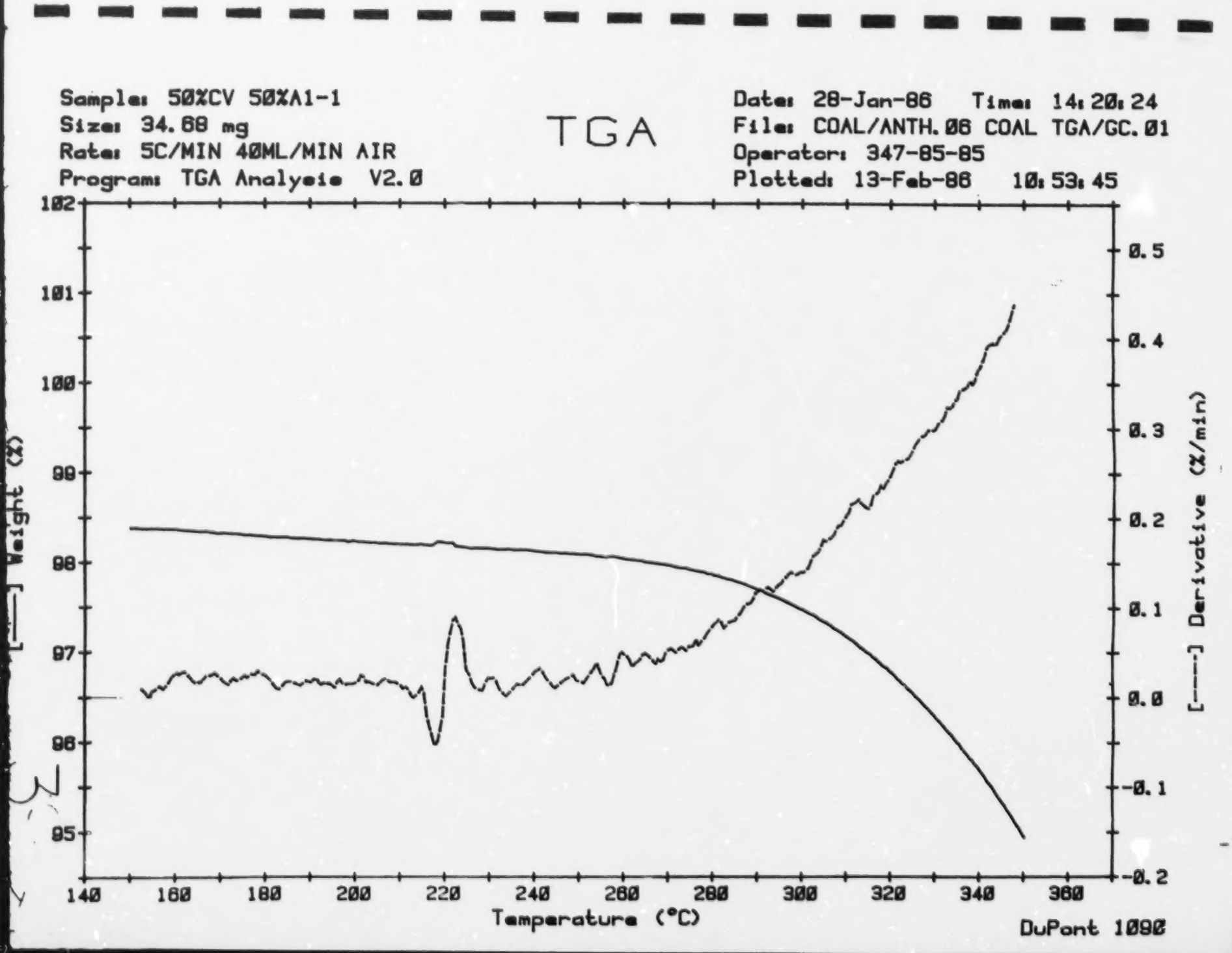

Sample: 50%CV 50%A1-1
Size: 34.68 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 28-Jan-86 Time: 14:20:24
File: COAL/ANTH.06 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 11:03:15
43.4°C 1.73 % MOISTURE
(0.598 mg)
68.6°C
393.2°C
42.58 % COMBUSTION 1
(14.76 mg)
422.0°C
44.65 % COMBUSTION 2
(15.48 mg)
541.9°C
572.4°C
Residue
10.73 % ASH
(3.72 mg)
Temperature (°C)
[----] Derivative (%/min)
DuPont 1090

Sample: 50%CV 50%A1-1
Size: 34.68 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 28-Jan-86 Time: 14:20:24
File: COAL/ANTH.06 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 11:10:32

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	43.4	68.6		0.60	1.73
COMBUSTION 1	393.2	422.0		14.76	42.56
COMBUSTION 2		541.9	572.4	15.48	44.65
ASH	Residue at 724.8 °C			3.72	10.73

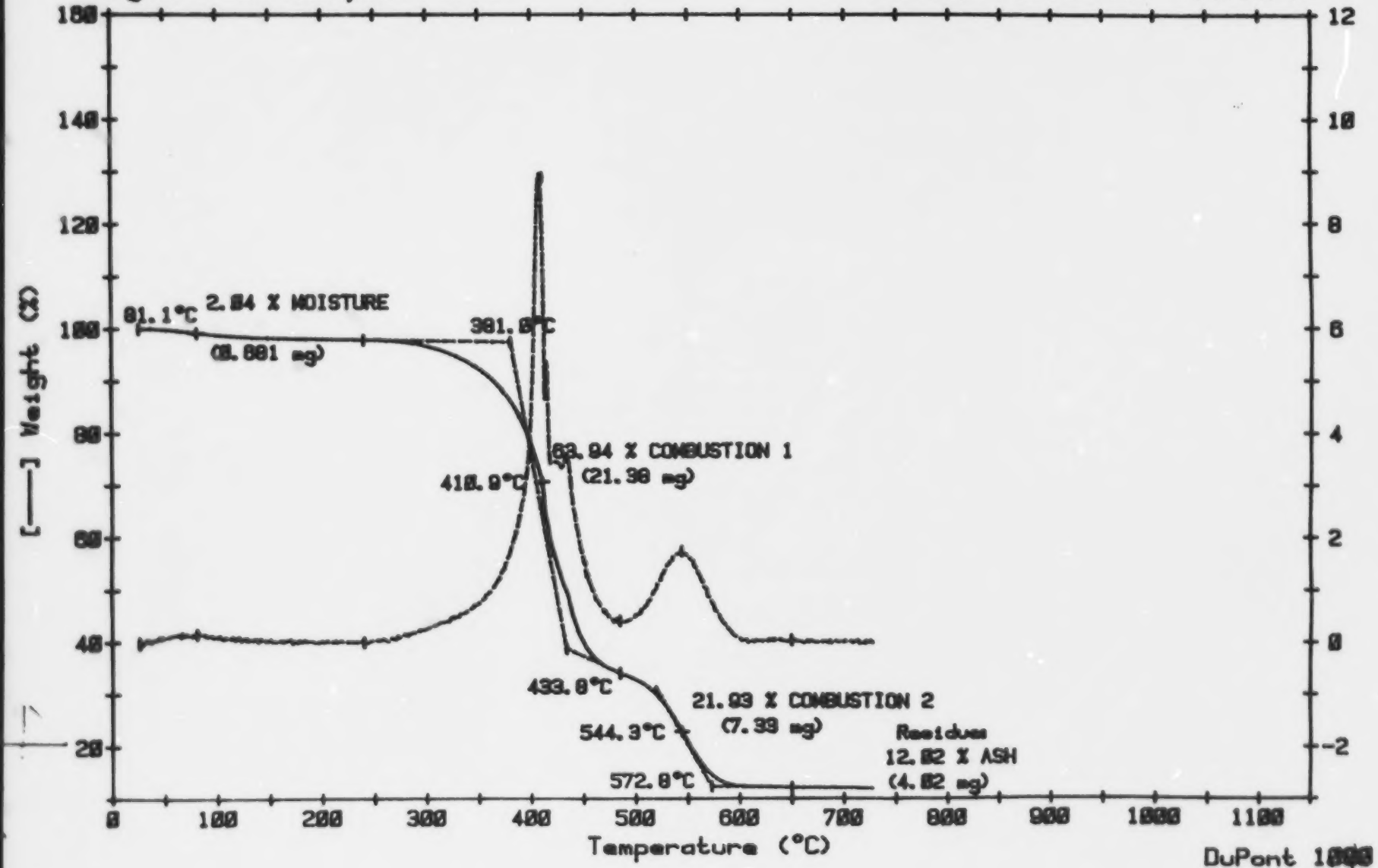
Modified Sample Weight: 34.67 mg


Sample: 50%CV 50%A1-1
Size: 34.68 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 28-Jan-86 Time: 14:20:24
File: COAL/ANTH.06 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 10:53:45
[——] Weight (%)
[- - -] Derivative (%/min)
Temperature (°C)
DuPont 1090
102
101
100
99
98
97
96
95
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
140
160
180
200
220
240
260
280
300
320
340
360

Sample: 25%A1 75%CV
Size: 33.43 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

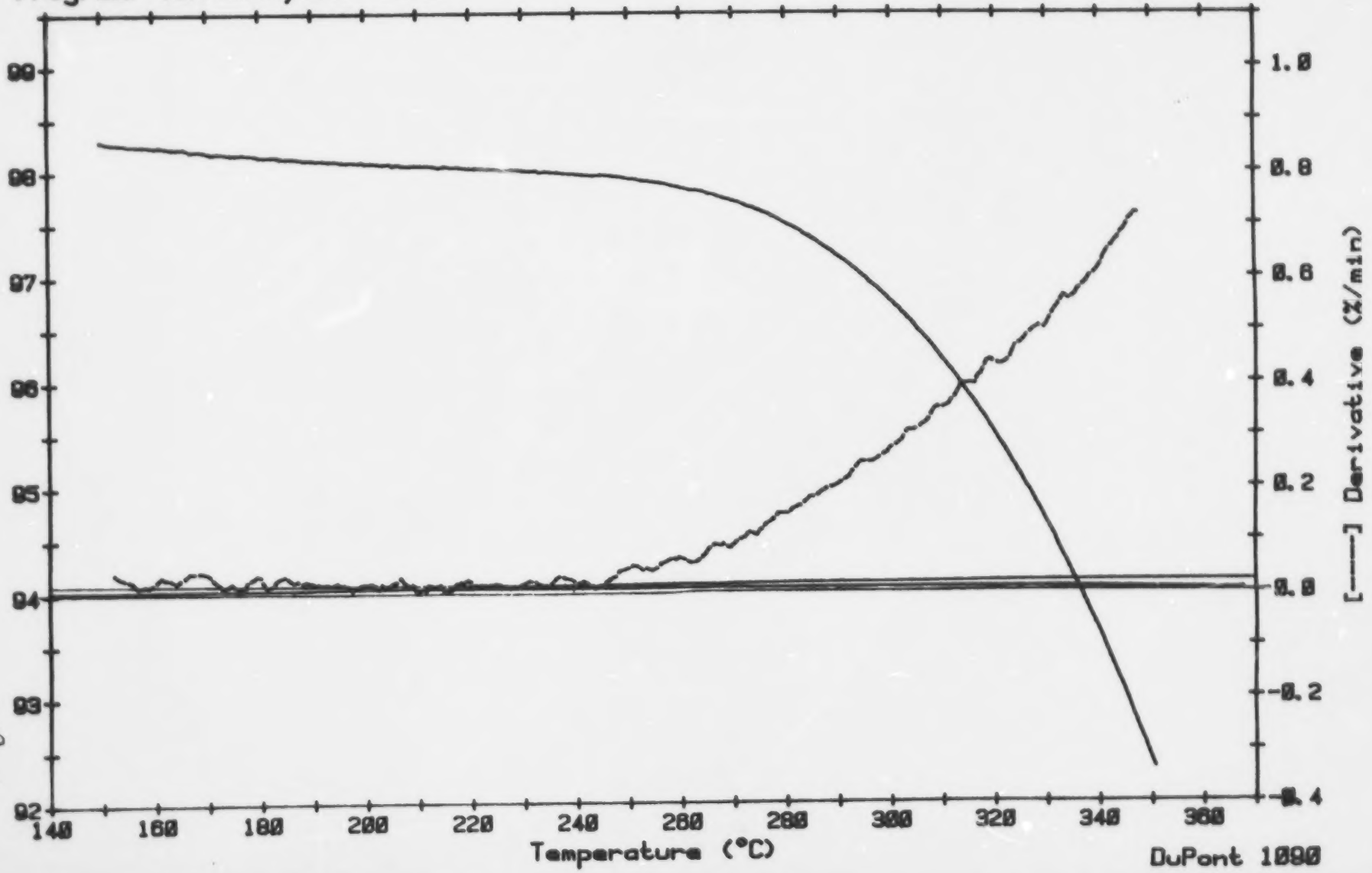
Date: 17-Feb-86 Time: 9:37:13
File: COAL/ANTH.24 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 17-Feb-86 14:14:47



Sample: 25%A1 75%CV
Size: 33.43 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

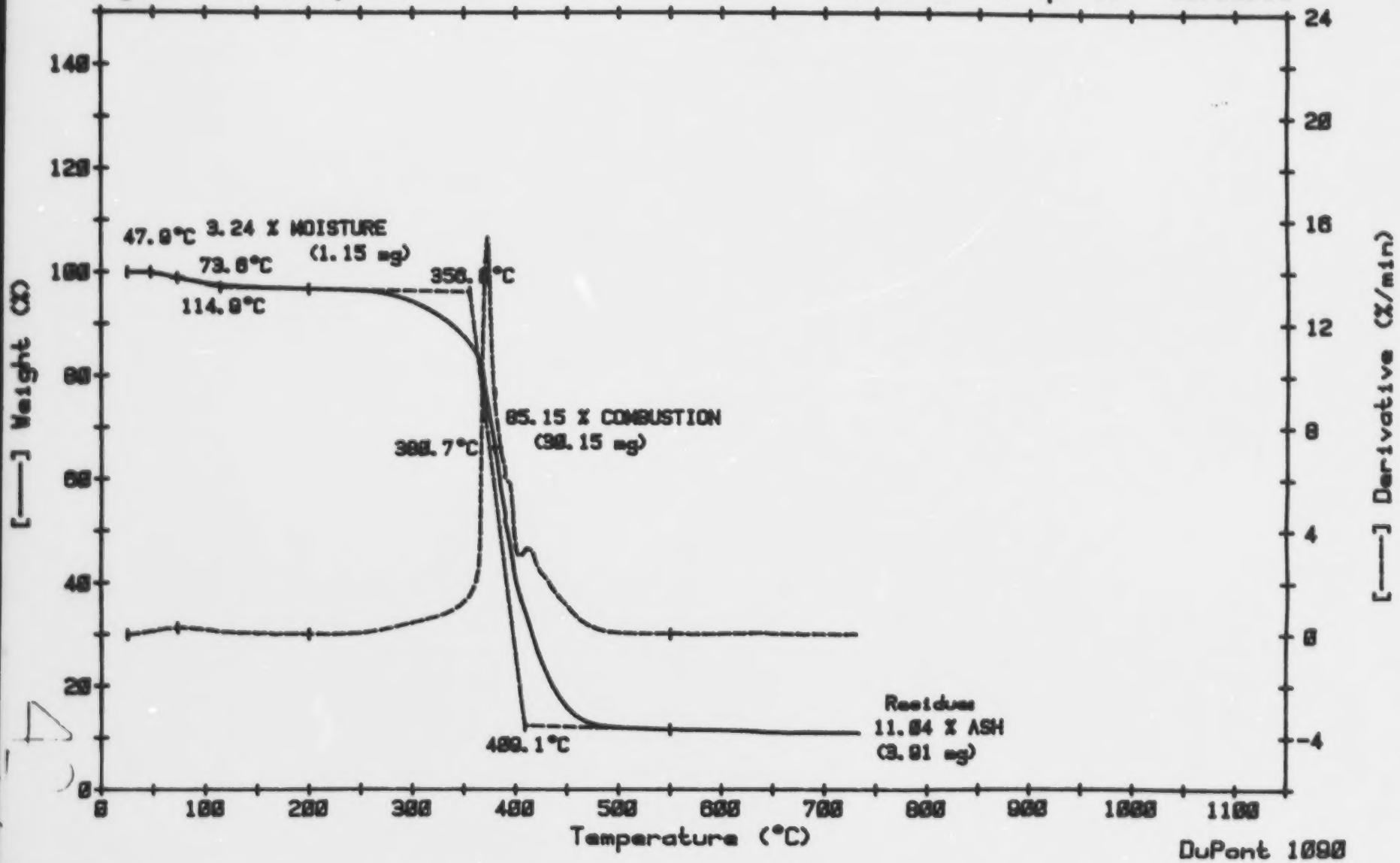
Date: 17-Feb-88 Time: 9:37:13
File: COAL



Sample: 100% CV
Size: 35.41 mg
Rate: 5C/MIN
Program: TGA Analysis V2.0

TGA

Date: 23-Jan-88 Time: 10:32:04
File: COAL/ANTH.03 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 24-Apr-88 12:38:16



DuPont 1090

Sample: 100% CV
Size: 35.41 mg
Rate: 5C/MIN
Program: TGA Analysis V2.0

Date: 23-Jan-86 Time: 10:32:04
File: COAL/ANTH.03 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 24-Apr-86 12:45:18

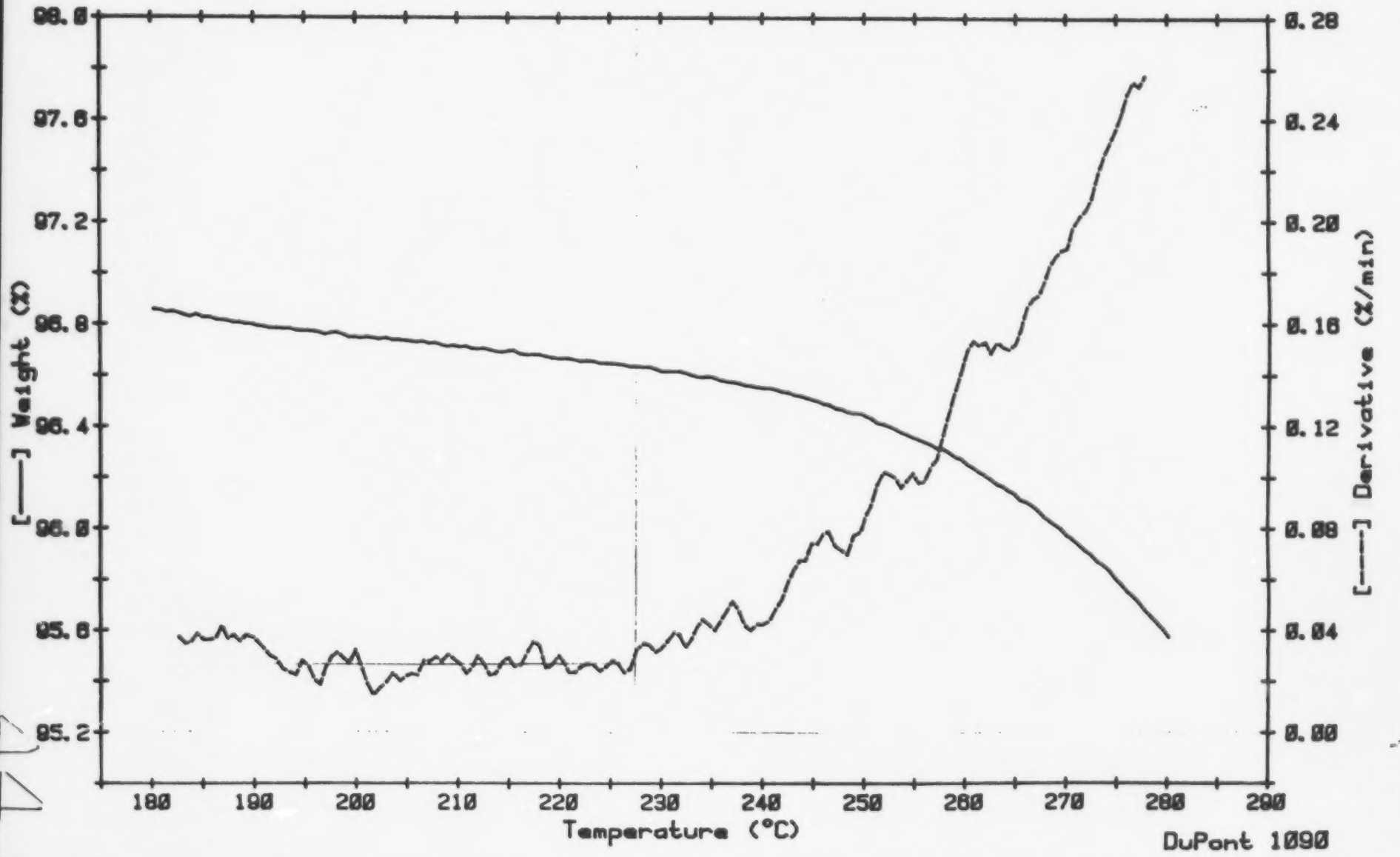
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	47.9	73.6	114.9	1.15	3.24
COMBUSTION	356.0	380.7	408.1	30.15	85.15
ASH	Residue at 737.7 °C			3.91	11.04

Modified Sample Weight: 35.41 mg

C4

Sample: 100% CV
Size:

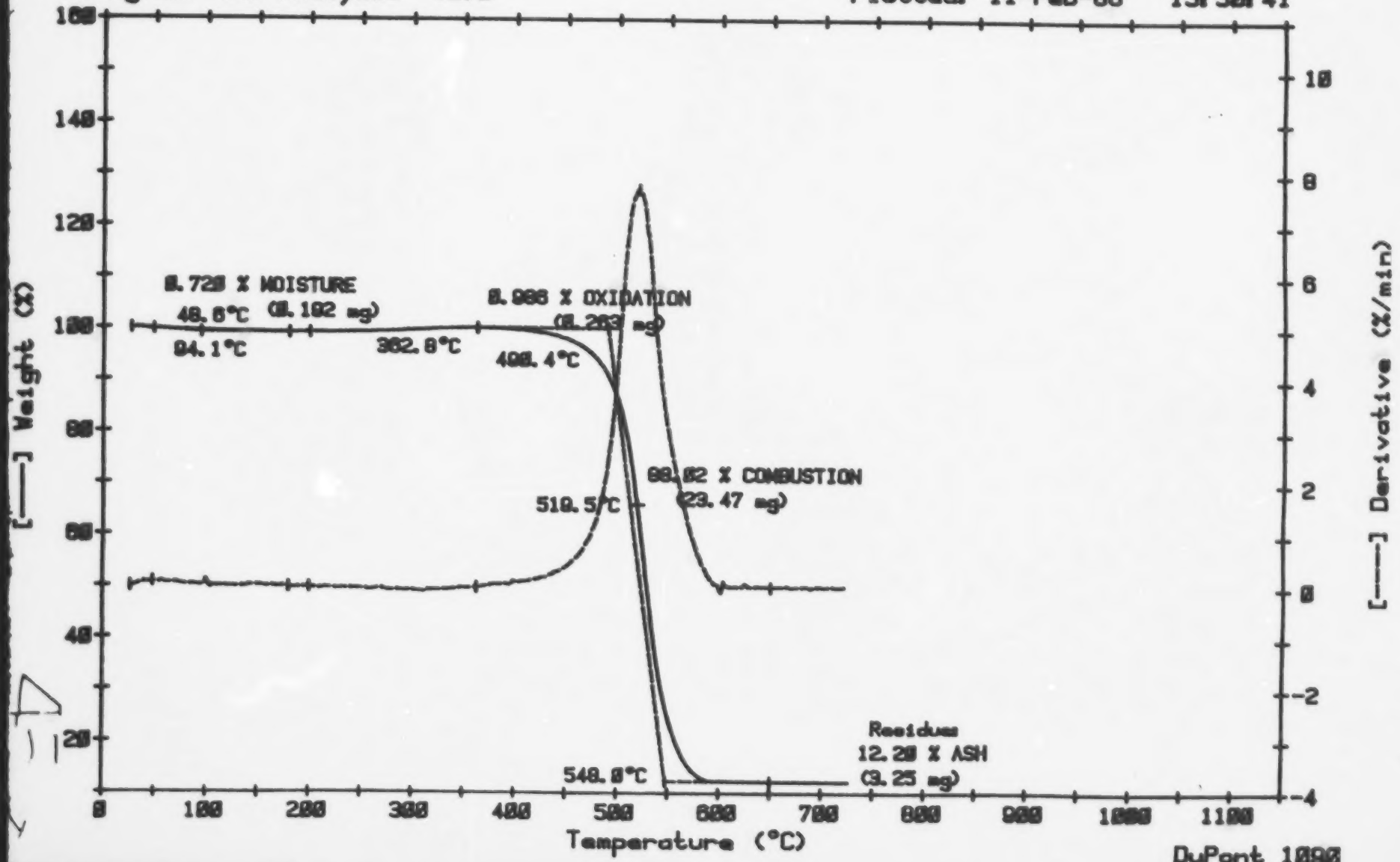
TGA



Sample: 100% A2-2
Size: 28.67 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 31-Jan-88 Time: 14:51:38
File: COAL/ANTH.10 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-88 15:50:41



Sample: 100% A2-2
Size: 26.67 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 31-Jan-86 Time: 14:51:38
File: COAL/ANTH.10 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 15:58:56

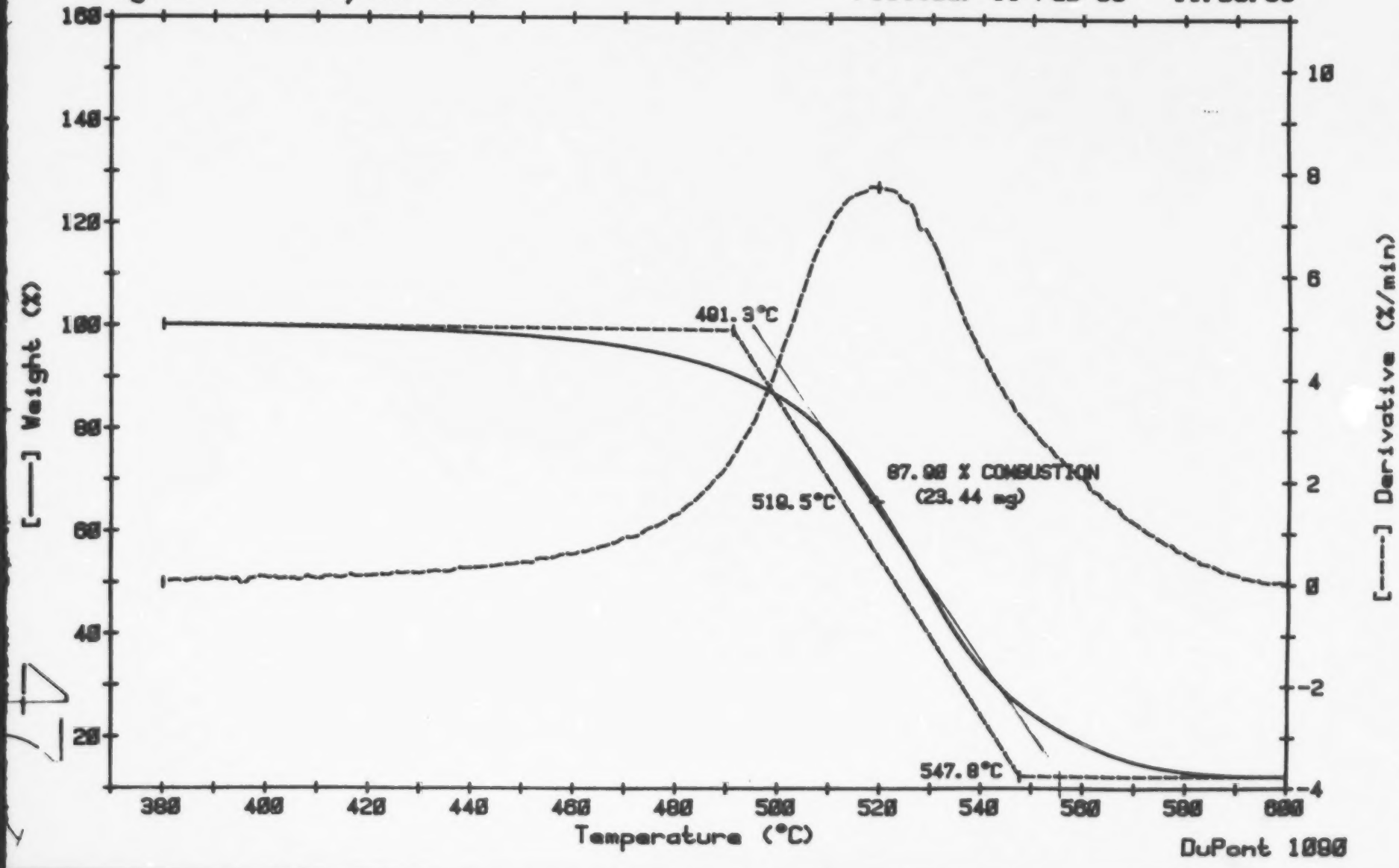
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		48.6	94.1	0.19	0.72
OXIDATION		362.8		0.26	0.99
COMBUSTION	490.4	519.5	548.2	23.47	88.02
ASH	Residue at 726.0 °C			3.25	12.20

Modified Sample Weight: 26.67 mg

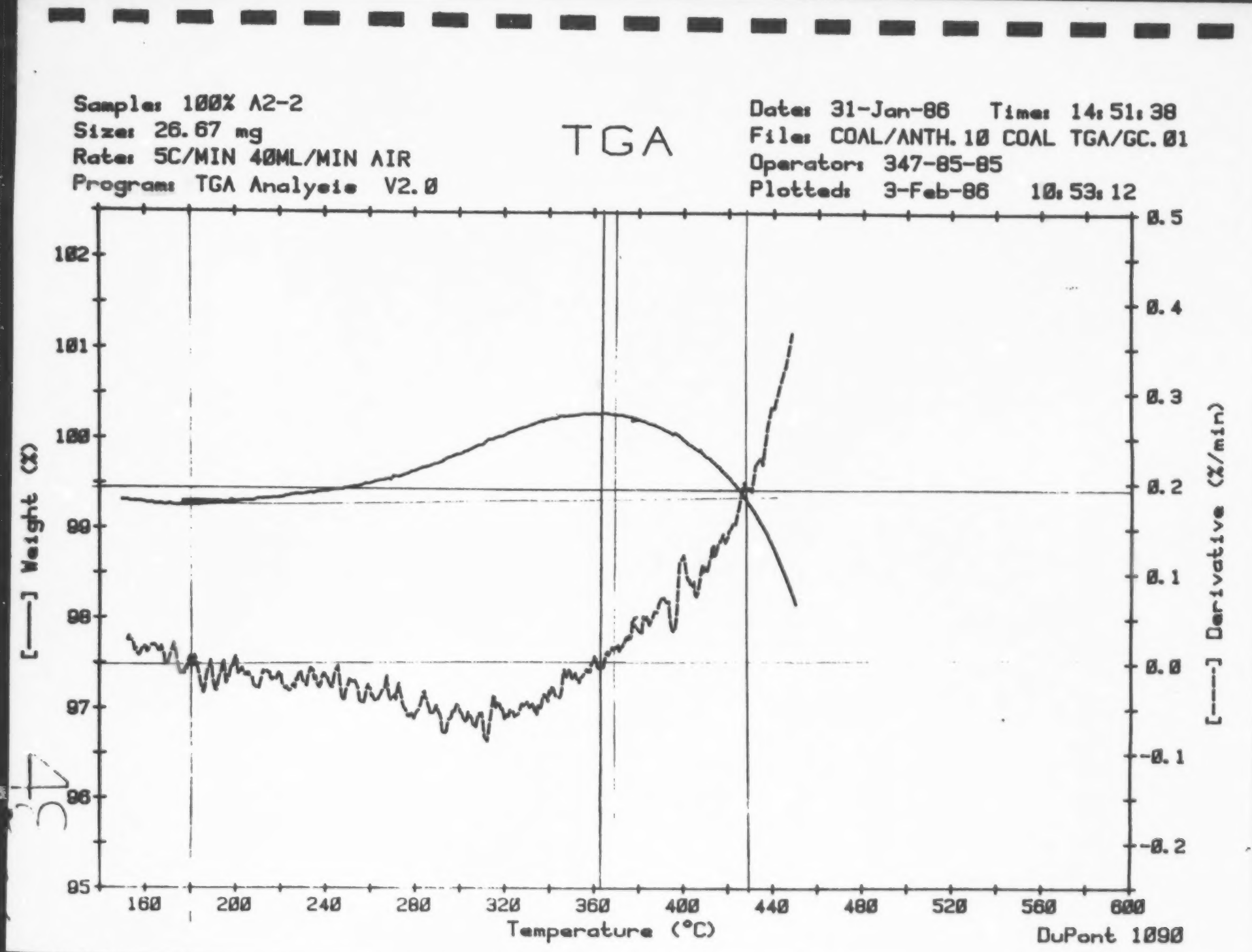
Sample: 100% A2-2
Size: 26.67 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

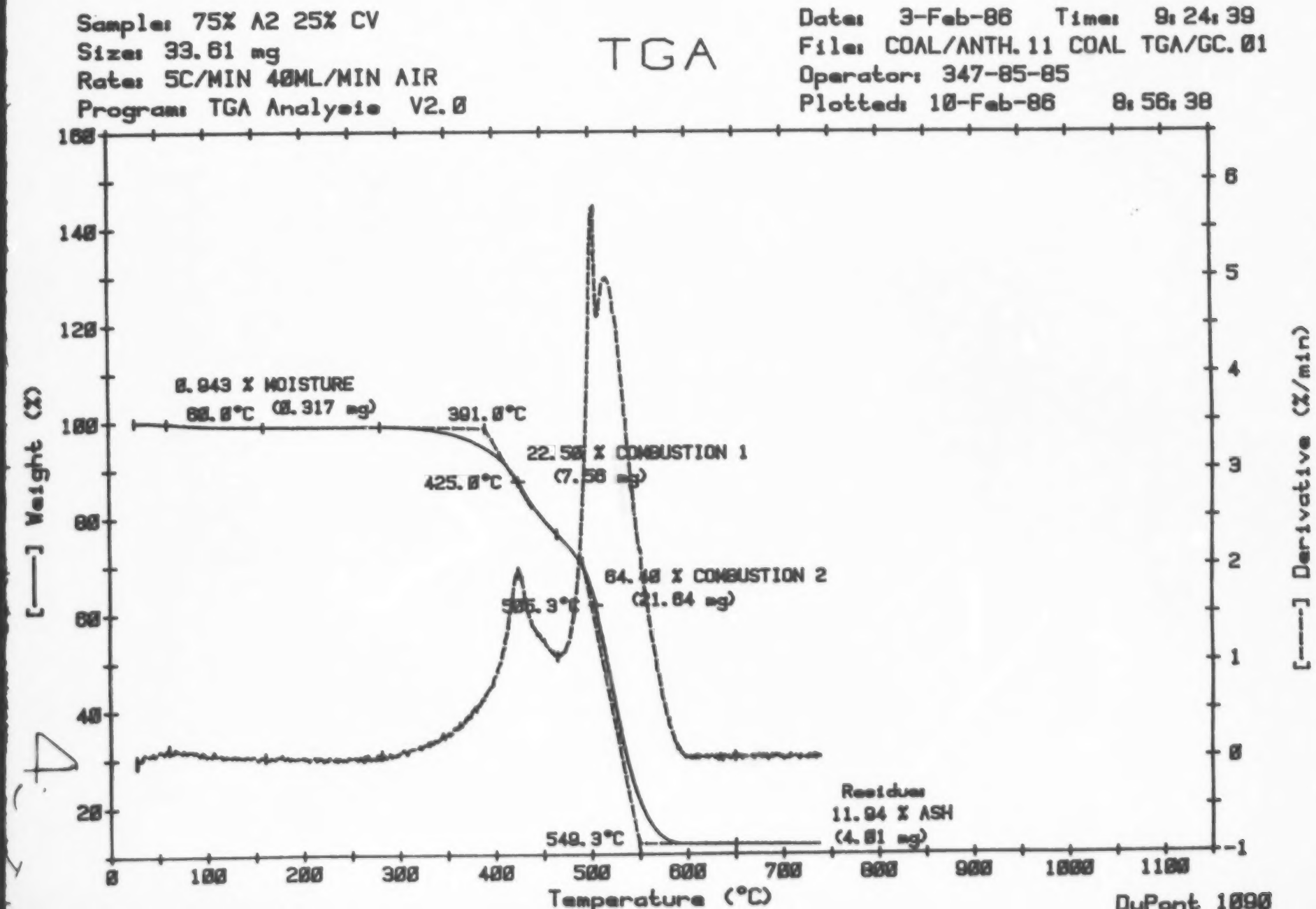
TGA

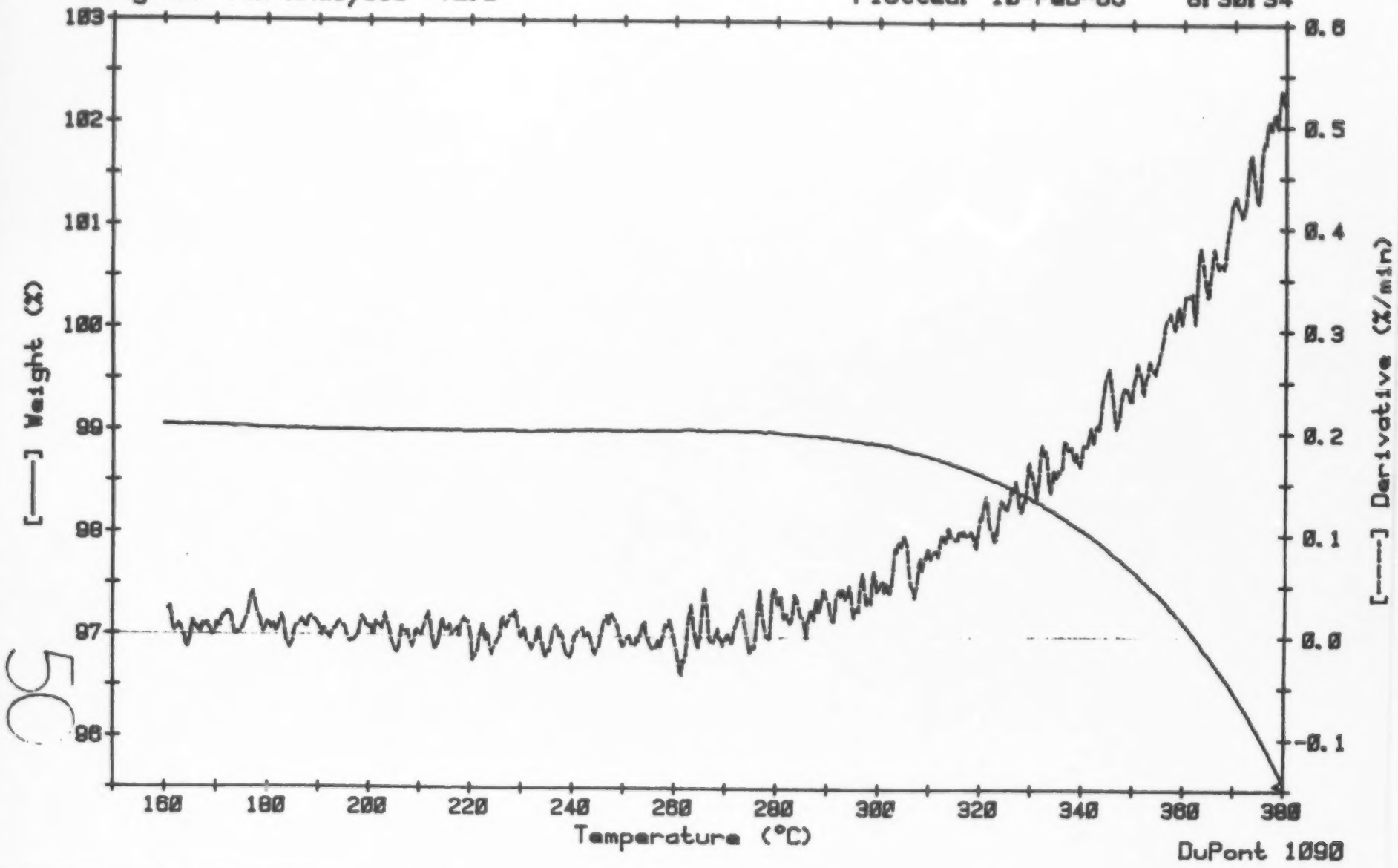
Date: 31-Jan-86 Time: 14:51:38
File: COAL/ANTH.10 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 11:09:35



DuPont 1090


Sample: 100% A2-2
Size: 26.67 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 31-Jan-86 Time: 14:51:38
File: COAL/ANTH.10 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 3-Feb-86 10:53:12
[——] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
DuPont 1090
102
101
100
99
98
97
96
95
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
160
200
240
280
320
360
400
440
480
520
560
600


Sample: 75% A2 25% CV
Size: 33.61 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 3-Feb-86 Time: 9:24:39
File: COAL/ANTH.11 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 8:56:38
0.943 % MOISTURE
88.0°C (0.317 mg)
391.0°C
22.50 % COMBUSTION 1
(7.56 mg)
425.0°C
64.40 % COMBUSTION 2
(21.64 mg)
505.3°C
Residue
11.94 % ASH
(4.01 mg)
549.3°C
[——] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
DuPont 1090


Sample: 75% A2 25% CV
Size: 33.61 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 3-Feb-86 Time: 9:24:39
File: COAL/ANTH.11 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 8:30:34
[——] Weight (%)
[——] Derivative (%/min)
Temperature (°C)
5C
DuPont 1090

Sample: 75% A2 25% CV
Size: 33.61 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 3-Feb-86 Time: 9:24:39
File: COAL/ANTH.11 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 8:47:30

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		60.0		0.32	0.94
COMBUSTION 1	391.0	425.0		7.56	22.50
COMBUSTION 2		505.3	549.3	21.64	64.40
ASH		Residue at 739.2 °C		4.01	11.94

Modified Sample Weight: 33.61 mg

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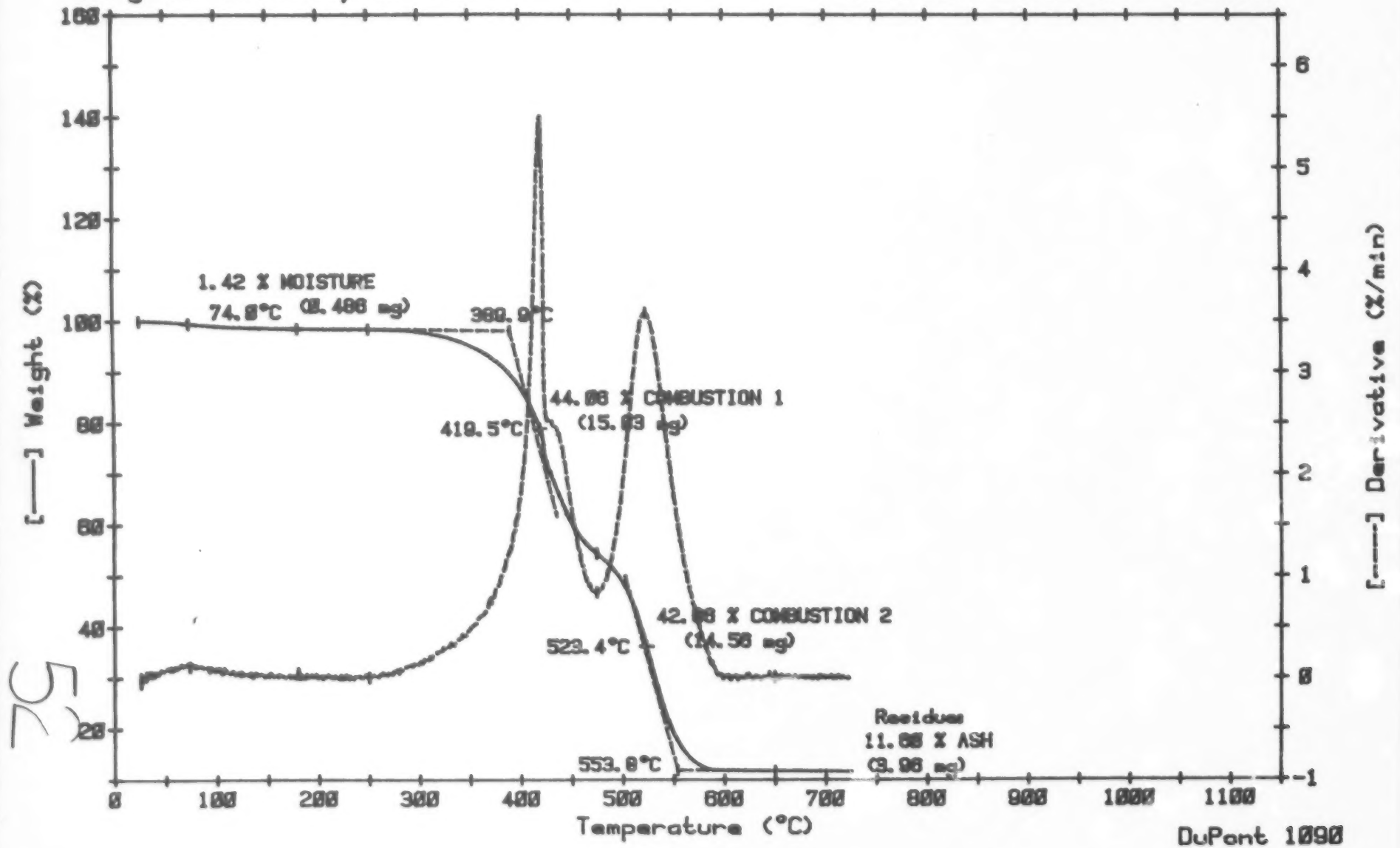
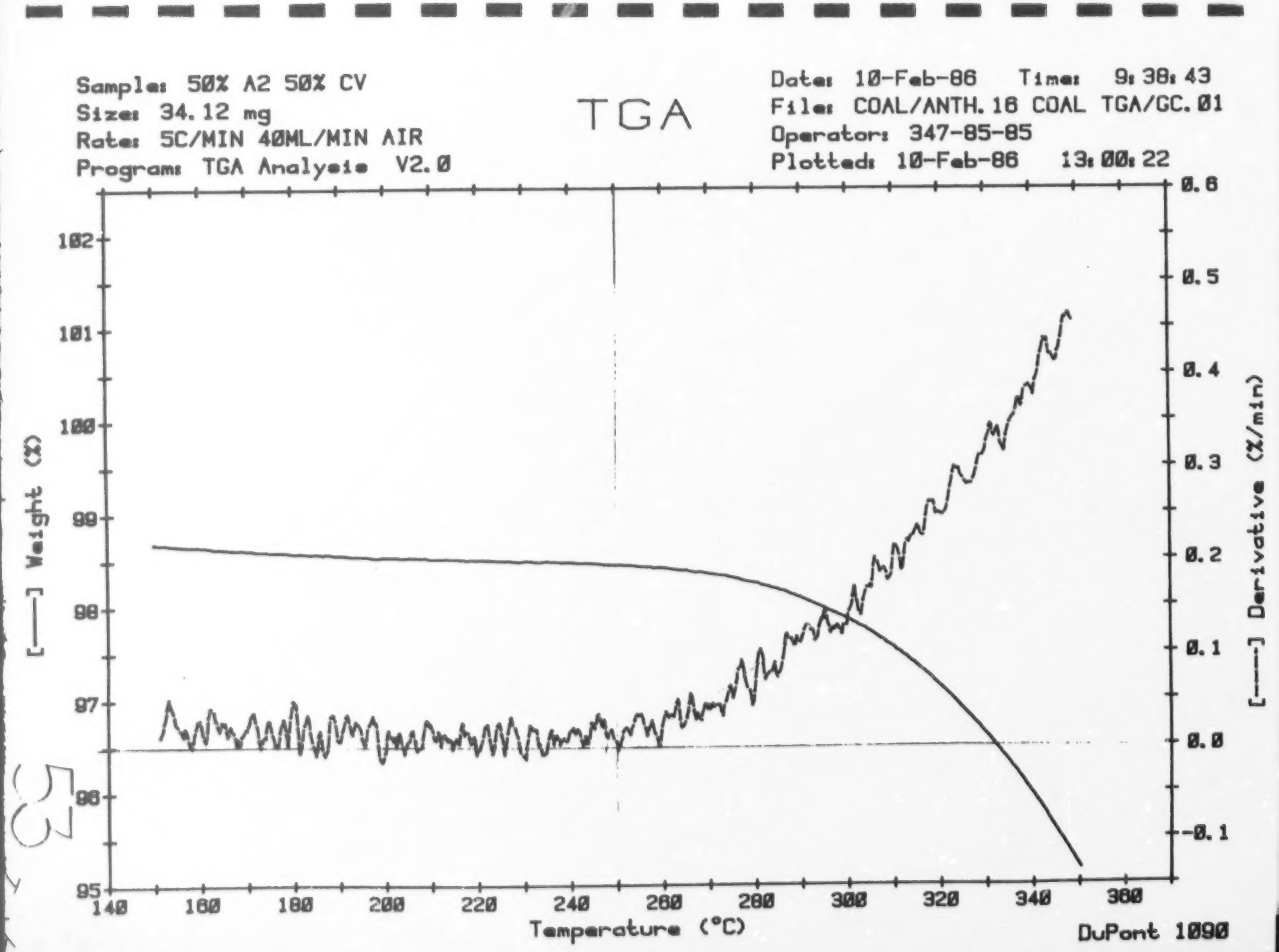
Sample: 50% A2 50% CV
Size: 34.12 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 10-Feb-86 Time: 9:38:43
File: COAL/ANTH.16 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 13:48:28



75


Sample: 50% A2 50% CV
Size: 34.12 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 10-Feb-86 Time: 9:38:43
File: COAL/ANTH.16 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 13:00:22
[——] Weight (%)
[——] Derivative (%/min)
Temperature (°C)
DuPont 1090
102
101
100
99
98
97
96
95
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
140
160
180
200
220
240
260
280
300
320
340
360

Sample: 50% A2 50% CV
Size: 34.12 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 10-Feb-86 Time: 9:38:43
File: COAL/ANTH.16 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 13:51:33

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		74.0		0.49	1.42
COMBUSTION 1	389.9	419.5		15.03	44.06
COMBUSTION 2		523.4	553.8	14.56	42.66
ASH	Residue at 726.9 °C			3.96	11.60

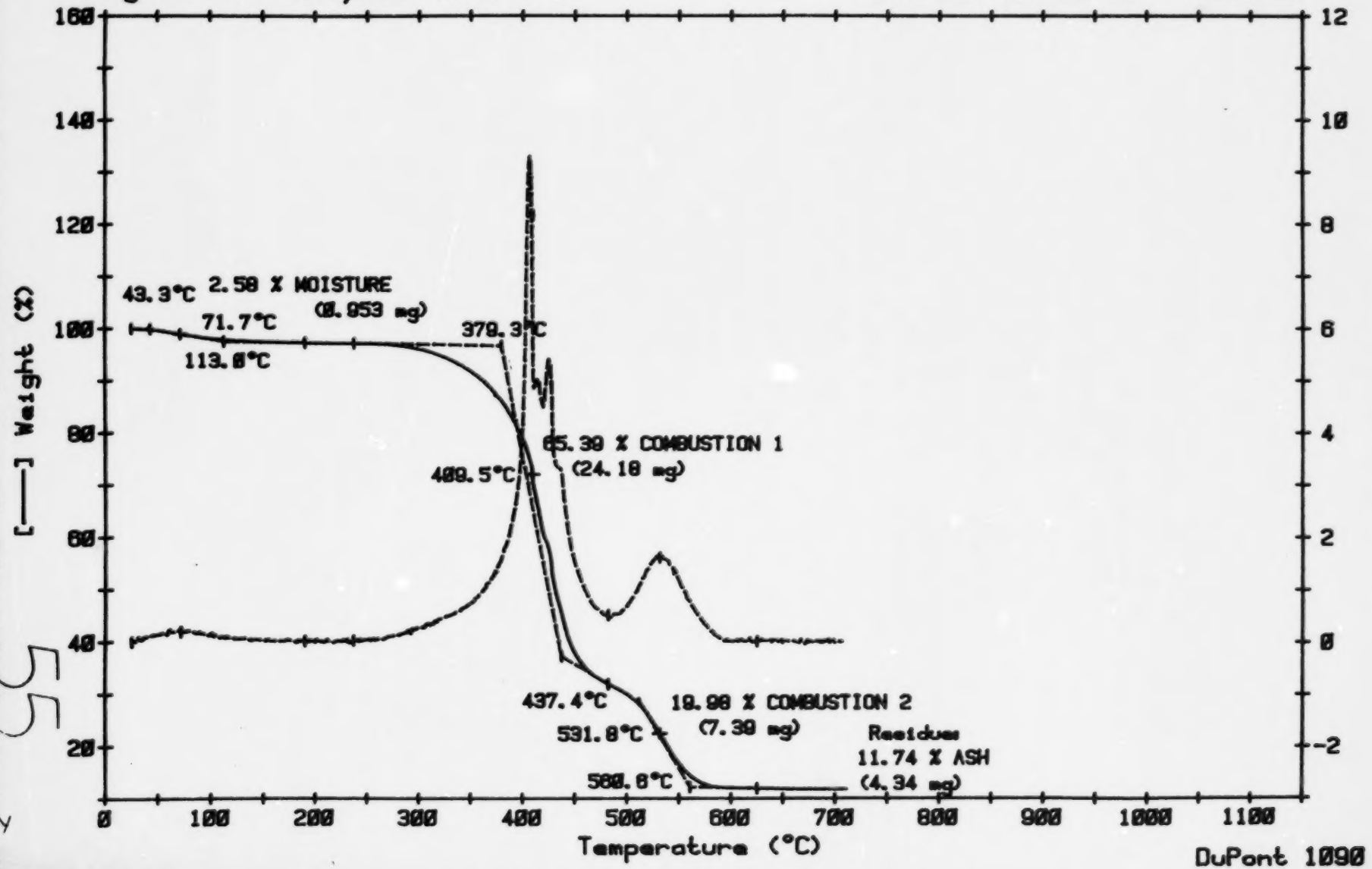
Modified Sample Weight: 34.12 mg

54

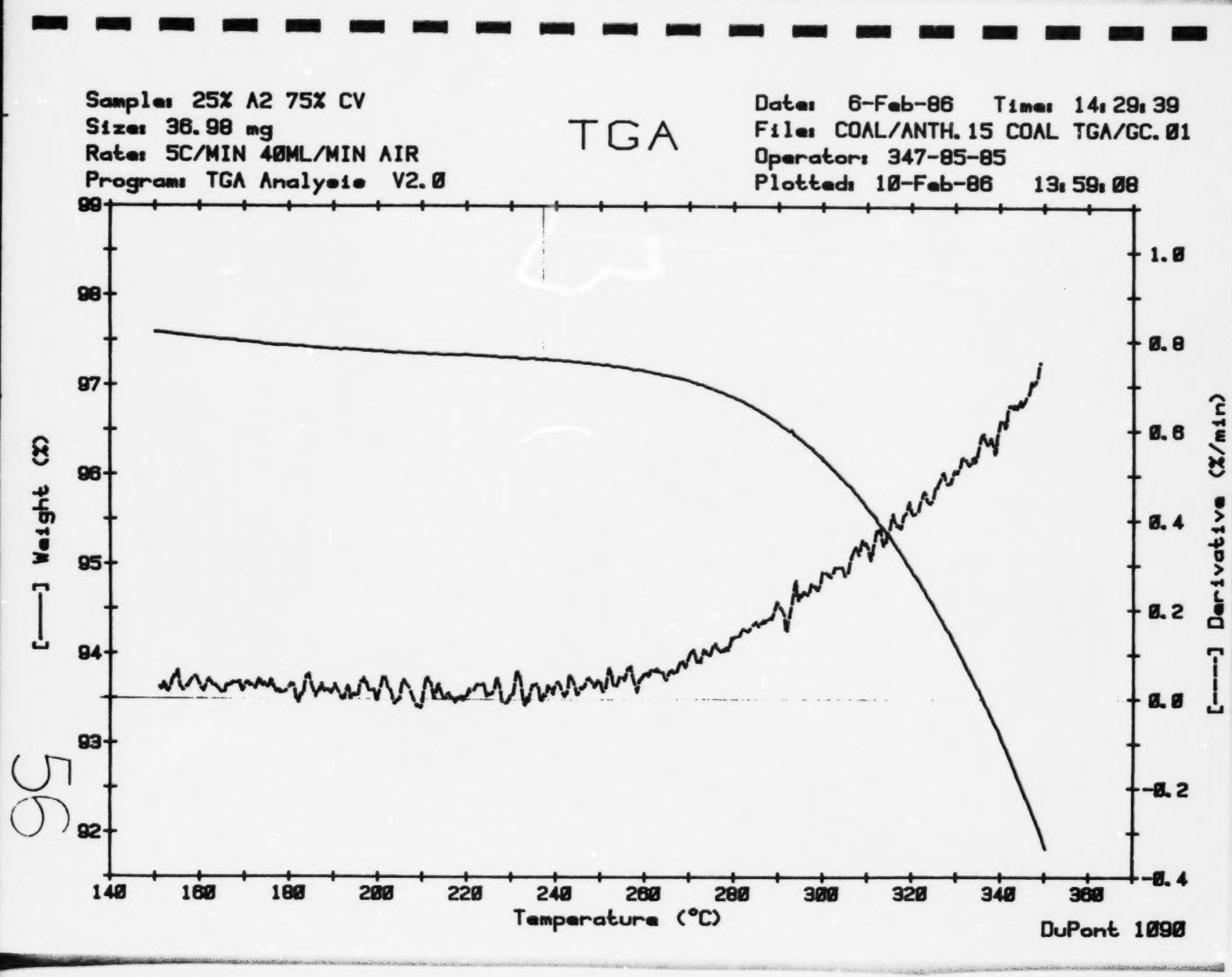
Sample: 25% A2 75% CV
Size: 36.98 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

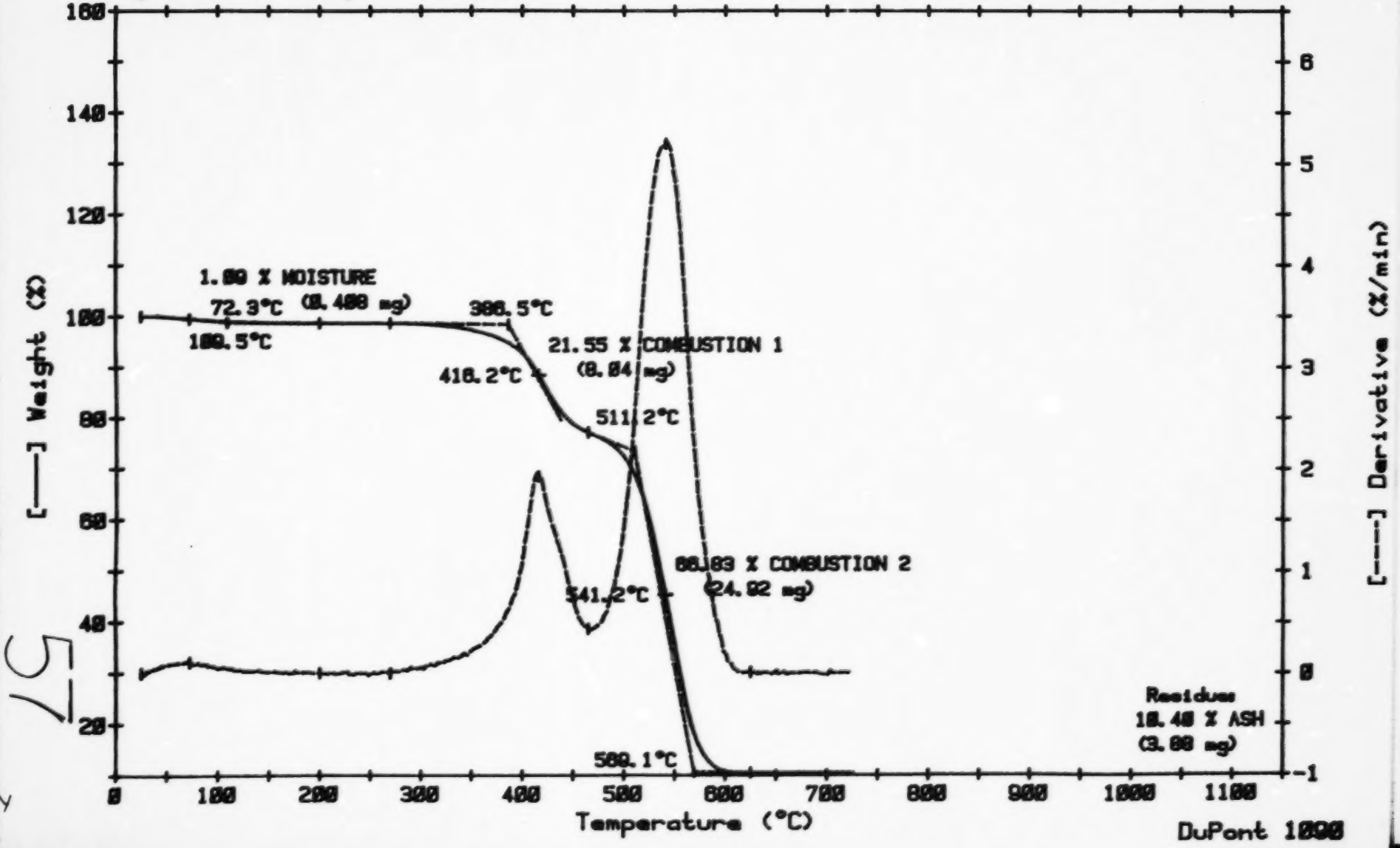
TGA

Date: 6-Feb-86 Time: 14:29:39
File: COAL/ANTH.15 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 14:47:49



DuPont 1090


Sample: 25% A2 75% CV
Size: 36.98 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 6-Feb-86 Time: 14:29:39
File: COAL/ANTH.15 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 10-Feb-86 13:59:08
[——] Weight (%)
[——] Derivative (%/min)
Temperature (°C)
DuPont 1090
99
98
97
96
95
94
93
92
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
140
160
180
200
220
240
260
280
300
320
340
360


Sample: 75%A1 25%OM
Size: 37.29 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 11-Feb-86 Time: 8:48:36
File: COAL/ANTH.17 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 13:59:33
1.89 % MOISTURE
72.3°C (0.488 mg)
189.5°C
386.5°C
21.55 % COMBUSTION 1
(8.04 mg)
418.2°C
511.2°C
66.83 % COMBUSTION 2
(24.92 mg)
541.2°C
589.1°C
Residue
10.48 % ASH
(3.88 mg)
[——] Weight (%)
[----] Derivative (%/min)
Temperature (°C)
DuPont 1090
57

Sample: 75%A1 25%OM
Size: 37.29 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 11-Feb-86 Time: 8:48:38
File: COAL/ANTH.17 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 14:02:52

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		72.3	109.5	0.41	1.09
COMBUSTION 1	386.5	416.2		8.04	21.55
COMBUSTION 2	511.2	541.2	569.1	24.92	66.83
ASH	Residue at 725.8 °C			3.88	10.40

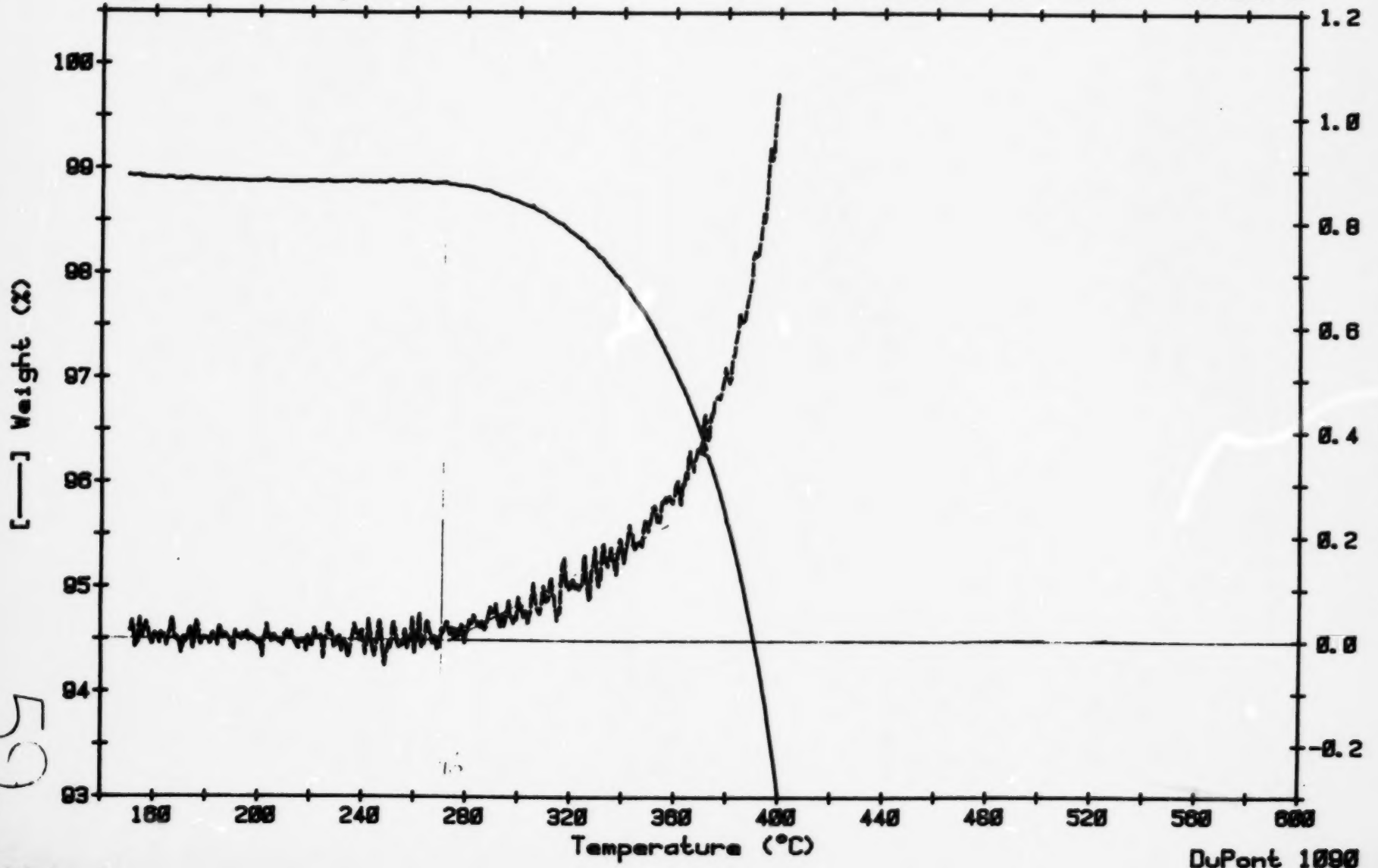
Modified Sample Weight: 37.29 mg

35

Sample: 75%A1 25%OM
Size: 37.29 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 11-Feb-86 Time: 8:48:36
File: COAL/ANTH.17 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 11-Feb-86 13:05:41

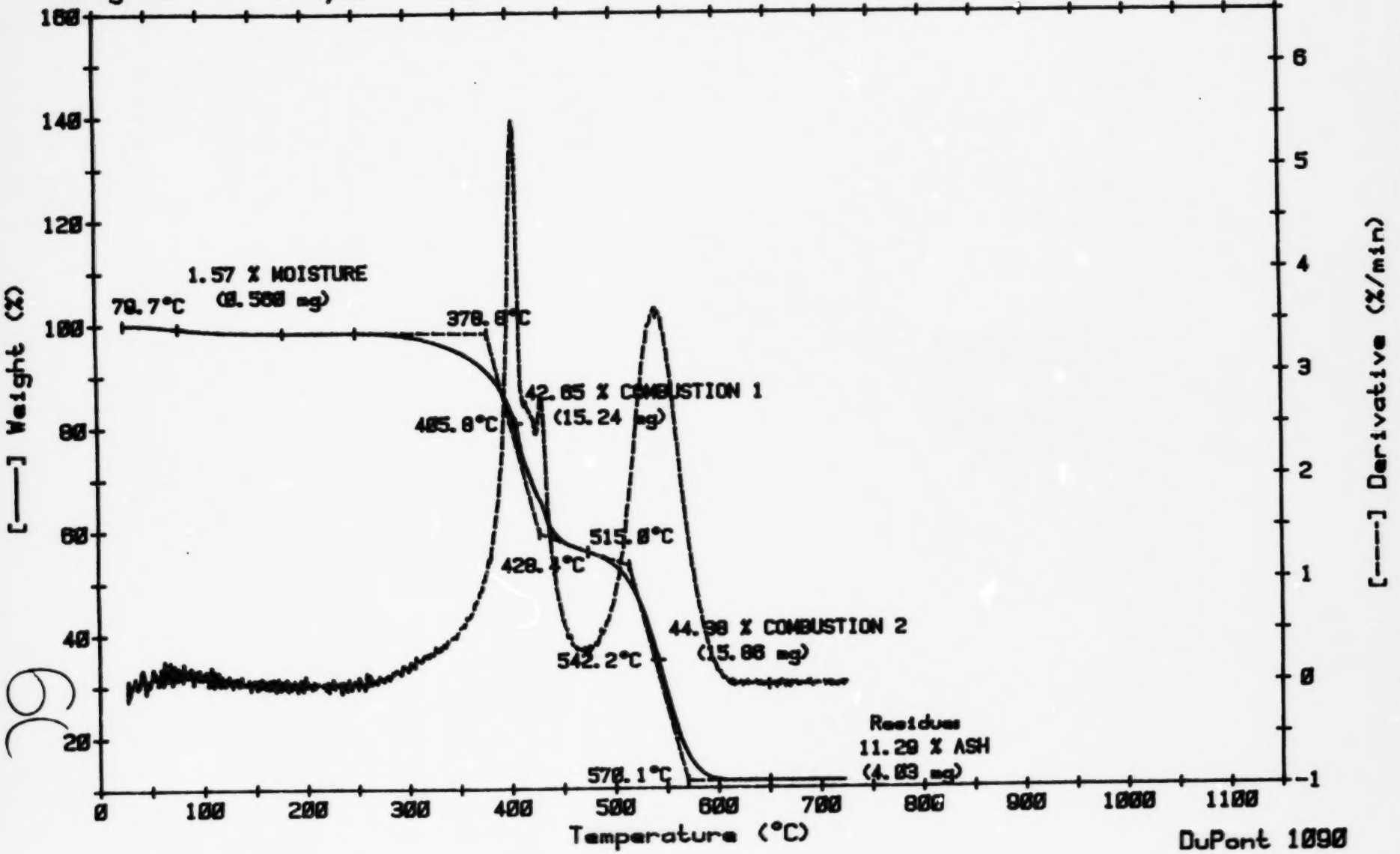


DuPont 1090

Sample: 50%A1 50%OM
Size: 35.73 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 11-Feb-86 Time: 13:41:55
File: COAL/ANTH.18 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 8:18:30



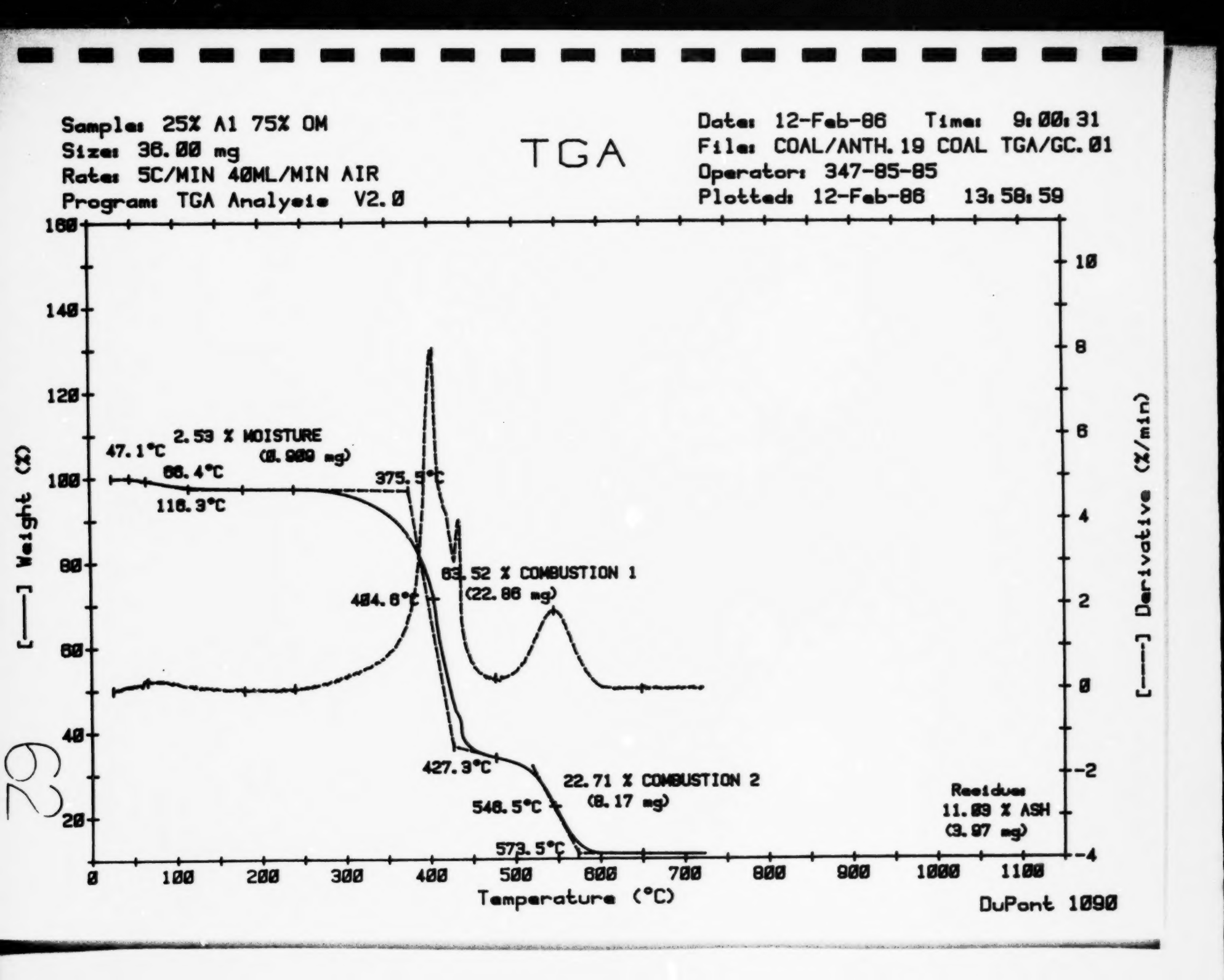
Sample: 50%A1 50%OM
Size: 35.73 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 11-Feb-86 Time: 13:41:55
File: COAL/ANTH.18 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 8:25:06

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		79.7		0.56	1.57
COMBUSTION 1	378.8	405.8	428.4	15.24	42.65
COMBUSTION 2	515.0	542.2	570.1	15.86	44.38
ASH	Residue at 725.7 °C			4.03	11.29

Modified Sample Weight: 35.73 mg

(5)

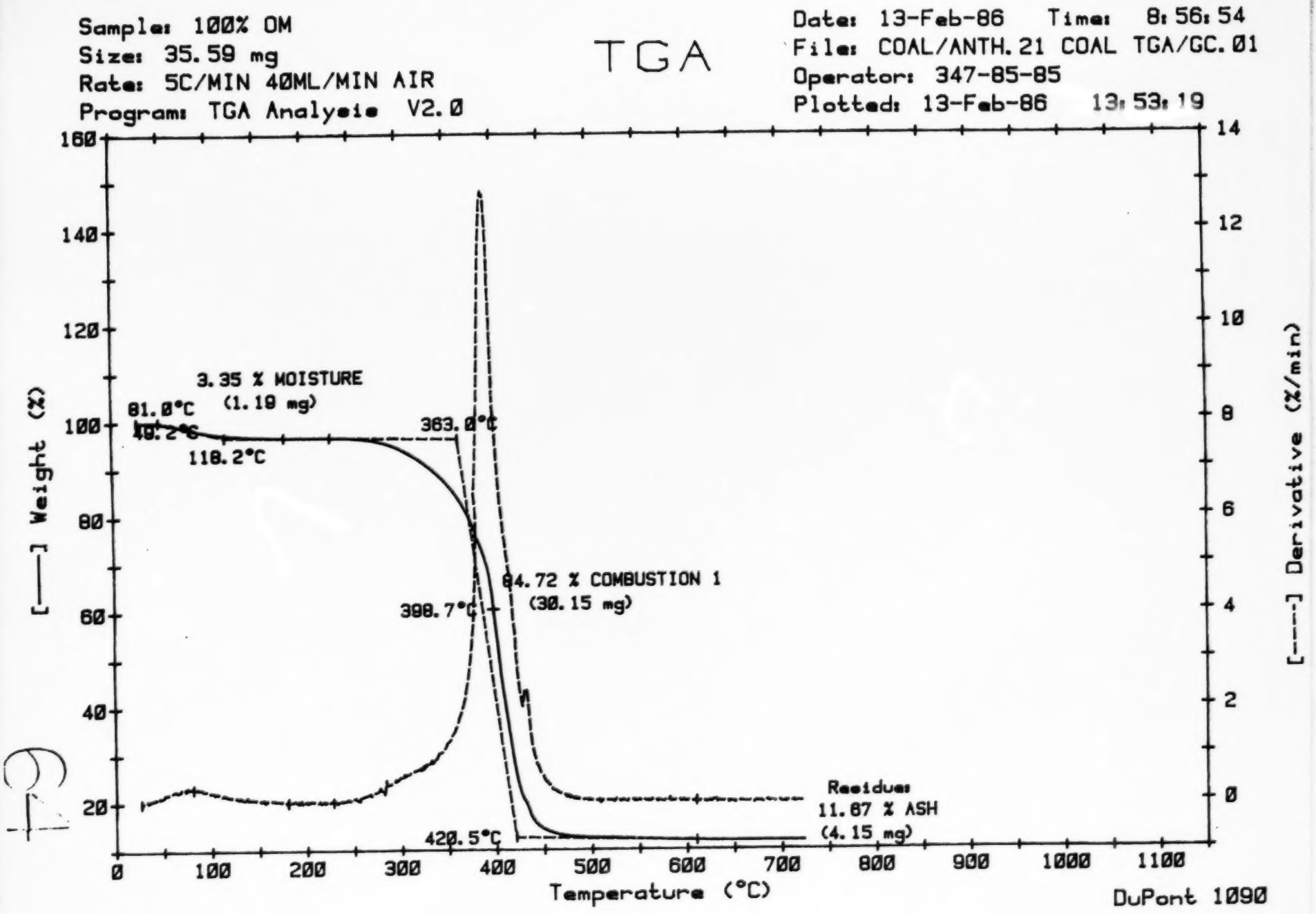

Sample: 25% A1 75% OM
Size: 36.00 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 12-Feb-86 Time: 9:00:31
File: COAL/ANTH.19 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 13:58:59
47.1°C
2.53 % MOISTURE
(0.909 mg)
66.4°C
116.3°C
375.5°C
63.52 % COMBUSTION 1
(22.86 mg)
484.6°C
427.3°C
22.71 % COMBUSTION 2
(8.17 mg)
548.5°C
573.5°C
Residue
11.09 % ASH
(3.97 mg)
[——] Weight (%)
[——] Derivative (%/min)
Temperature (°C)
DuPont 1090
79

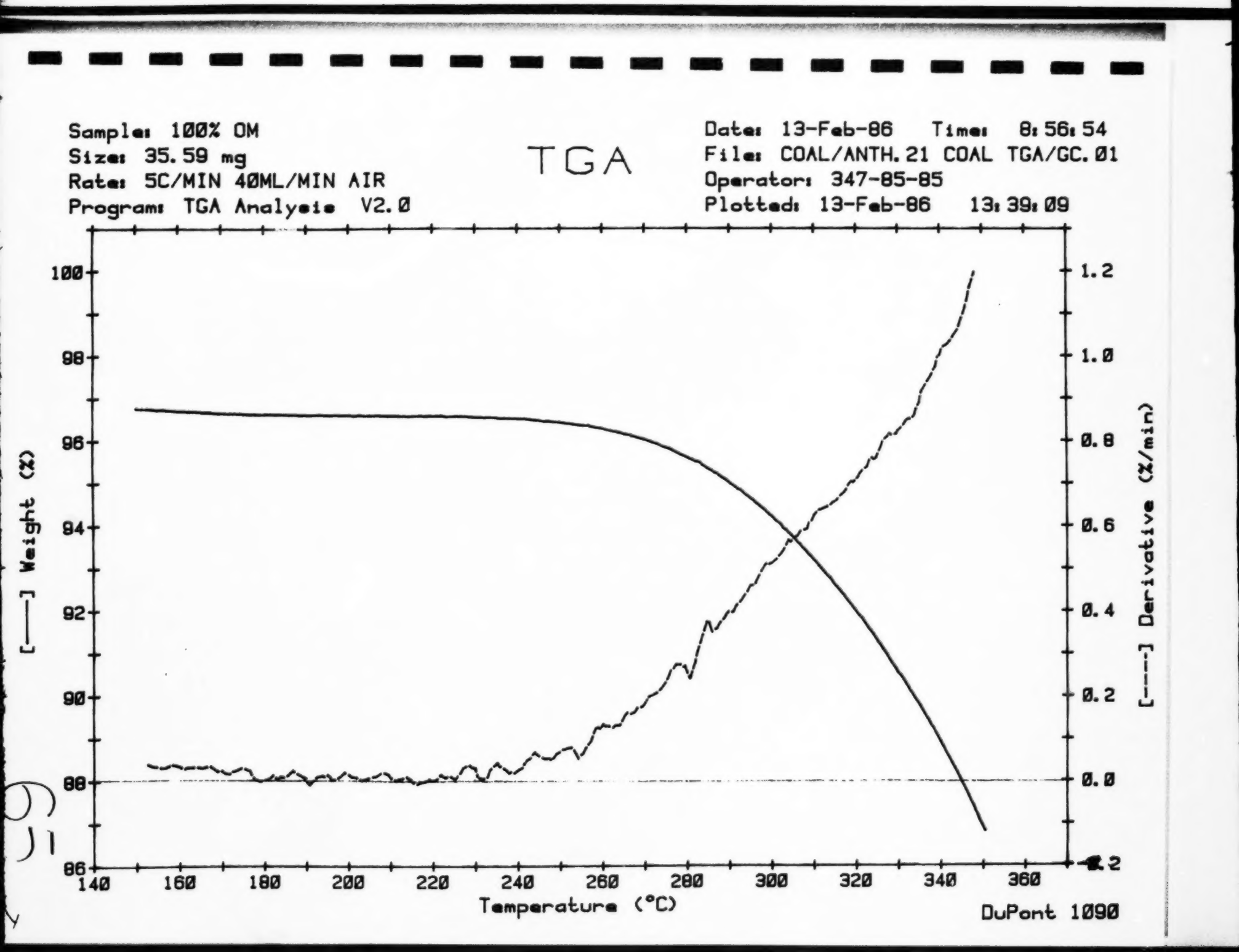
Sample: 25% A1 75% OM
Size: 36.00 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 12-Feb-86 Time: 9:00:31
File: COAL/ANTH.19 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 14:03:27

Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	47.1	66.4	116.3	0.91	2.53
COMBUSTION 1	375.5	404.6	427.3	22.86	63.52
COMBUSTION 2		546.5	573.5	8.17	22.71
ASH	Residue at 725.6 °C			3.97	11.03

Modified Sample Weight: 35.99 mg


Sample: 100% OM
Size: 35.59 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 13-Feb-86 Time: 8:56:54
File: COAL/ANTH.21 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 13:53:19
3.35 % MOISTURE
(1.19 mg)
81.0°C
118.2°C
363.0°C
84.72 % COMBUSTION 1
(30.15 mg)
398.7°C
Residue
11.67 % ASH
(4.15 mg)
420.5°C
[——] Weight (%)
[---] Derivative (%/min)
Temperature (°C)
DuPont 1090


Sample: 100% OM
Size: 35.59 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0
TGA
Date: 13-Feb-86 Time: 8:56:54
File: COAL/ANTH.21 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 13:39:09
[——] Weight (%)
[- - -] Derivative (%/min)
100
98
96
94
92
90
88
86
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
140
160
180
200
220
240
260
280
300
320
340
360
Temperature (°C)
DuPont 1090

Sample: 100% OM
Size: 35.59 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 13-Feb-86 Time: 8:56:54
File: COAL/ANTH.21 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 13:56:56

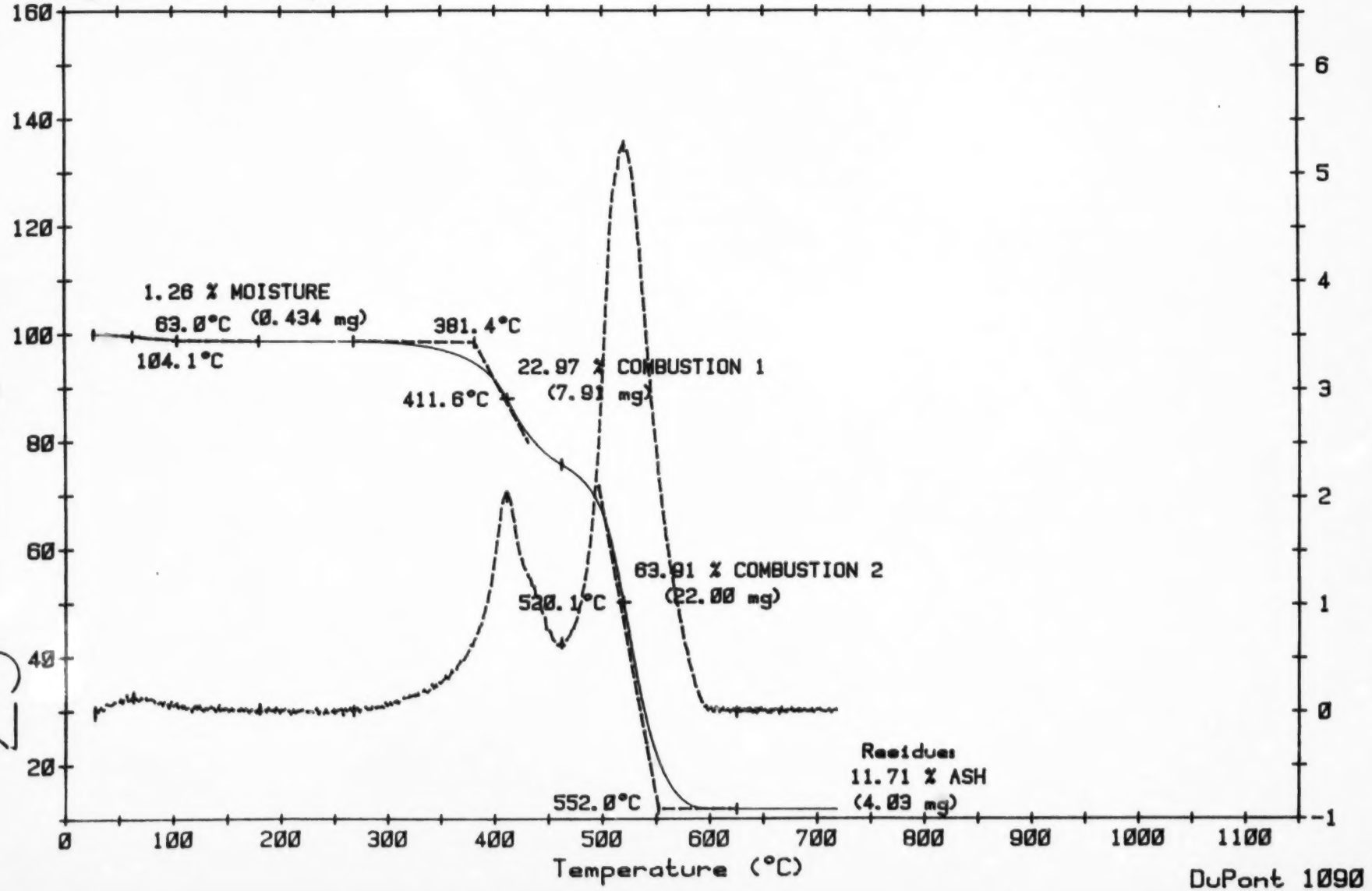
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	49.2	81.0	118.2	1.19	3.35
COMBUSTION 1	363.0	398.7	420.5	30.15	84.72
ASH	Residue at 726.5 °C			4.15	11.67

Modified Sample Weight: 35.58 mg

Sample: 75% A2 25% OM
Size: 34.43 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 12-Feb-86 Time: 13:31:34
File: COAL/ANTH.20 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 8:12:06



DuPont 1090

Sample: 75% A2 25% OM
Size: 34.43 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 12-Feb-86 Time: 13:31:34
File: COAL/ANTH.20 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 13-Feb-86 8:24:25

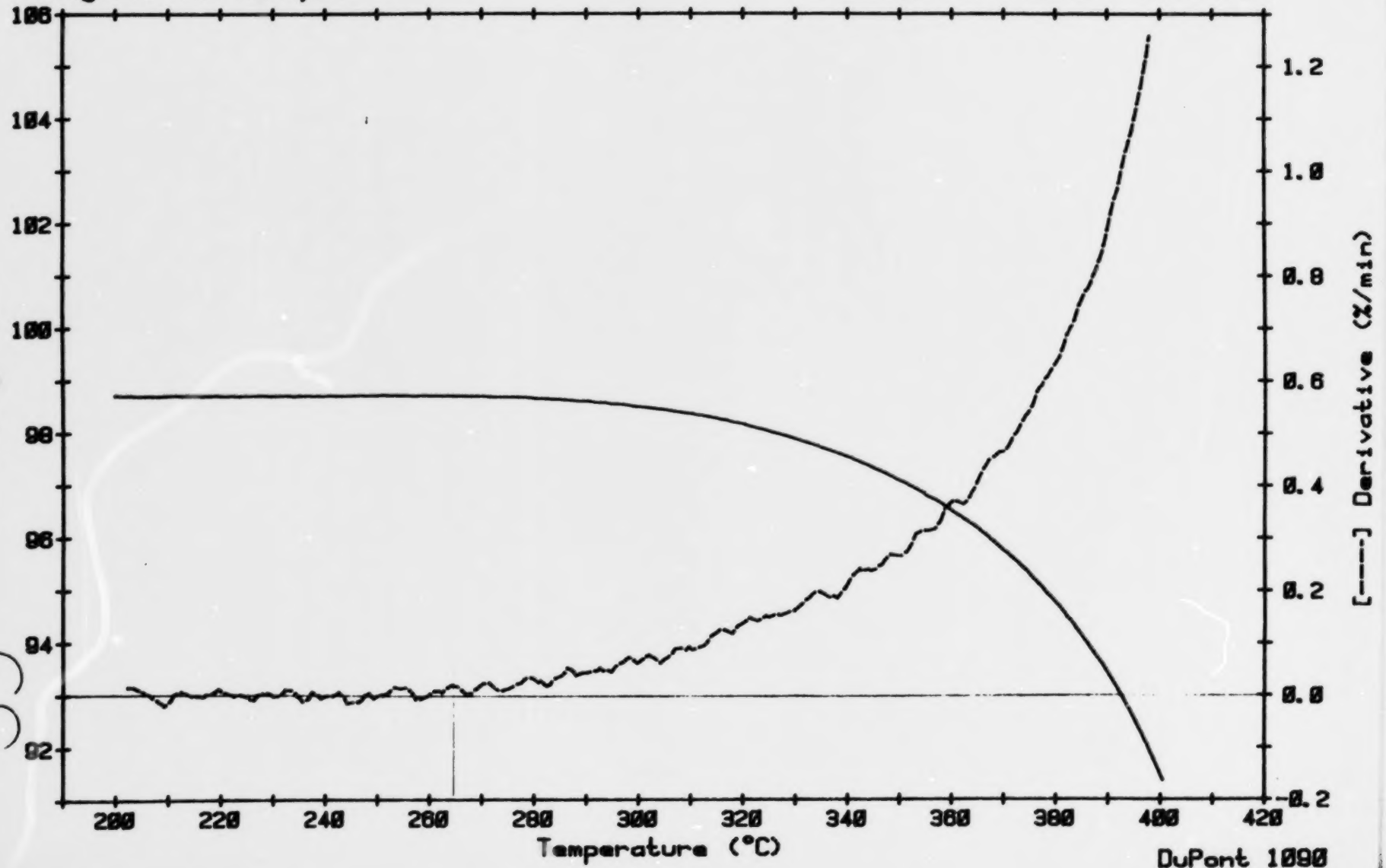
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE		63.0	104.1	0.43	1.26
COMBUSTION 1	381.4	411.6		7.91	22.97
COMBUSTION 2		520.1	552.0	22.00	63.91
ASH	Residue at 720.0 °C			4.03	11.71

Modified Sample Weight: 34.43 mg

Sample: 75% A2 25% OM
Size: 34.43 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 12-Feb-86 Time: 13:31:34
File: COAL/ANTH.20 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 12-Feb-86 16:15:55



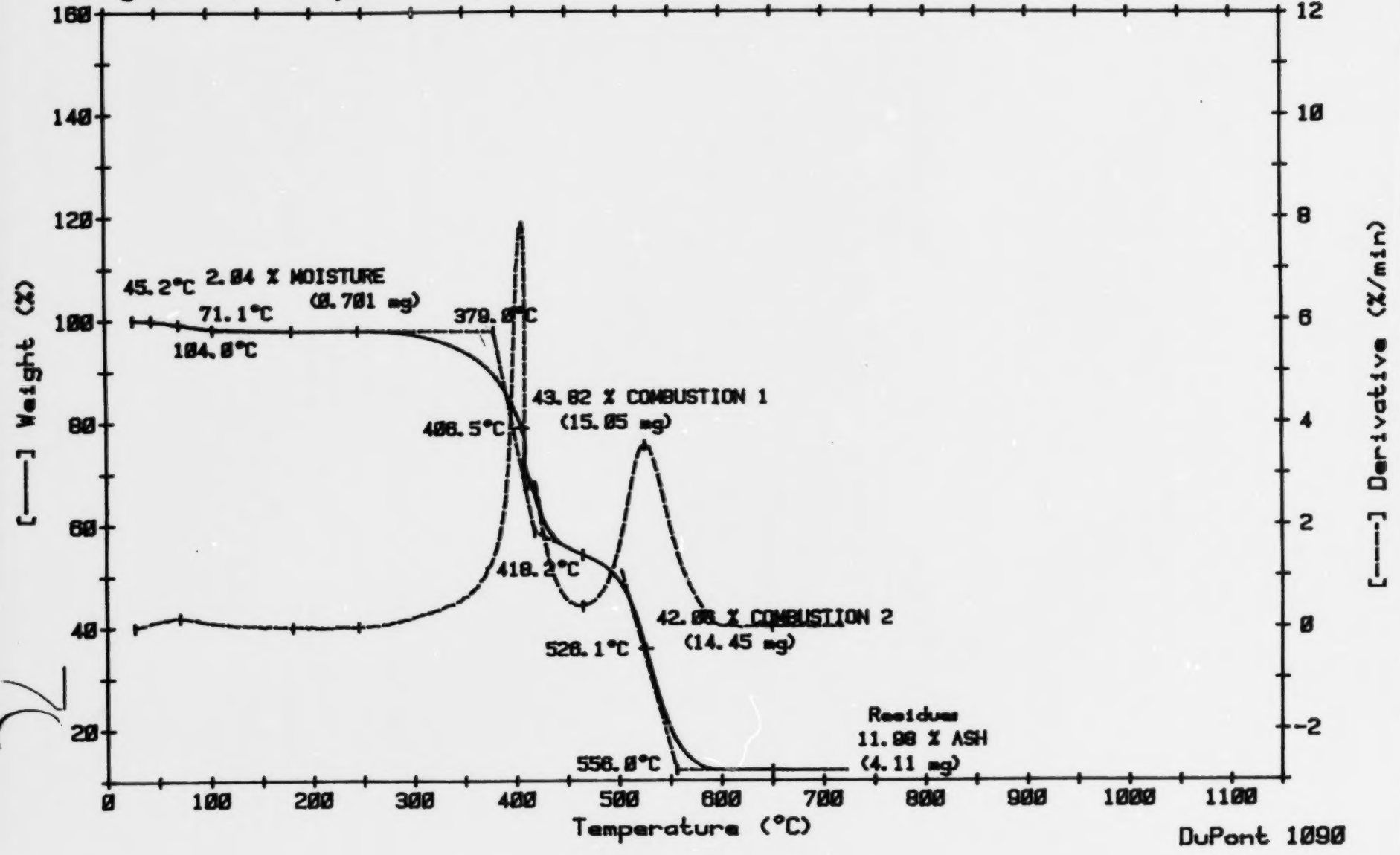
DuPont 1090

(39)

Sample: 50%A2 50%OM
Size: 34.35 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

Date: 13-Feb-86 Time: 13:56:56
File: COAL/ANTH.22 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 14-Feb-86 10:36:03



DuPont 1090

Sample: 50%A2 50%OM
Size: 34.35 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

Date: 13-Feb-86 Time: 13:56:56
File: COAL/ANTH.22 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 14-Feb-86 11:04:00

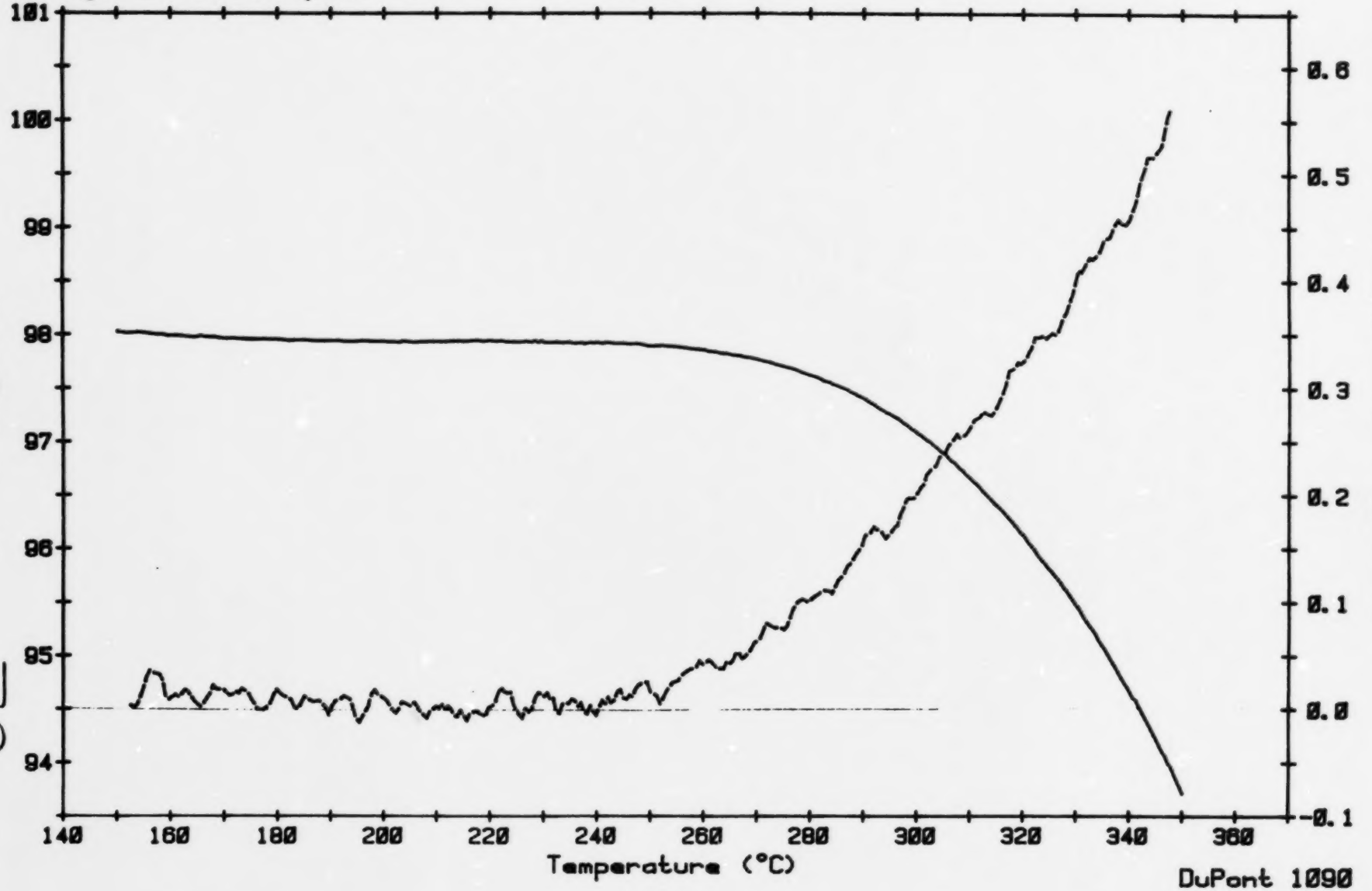
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	45.2	71.1	104.0	0.70	2.04
COMBUSTION 1	379.0	406.5	418.2	15.05	43.82
COMBUSTION 2		526.1	556.0	14.45	42.06
ASH		Residue at 722.2 °C		4.11	11.98

Modified Sample Weight: 34.35 mg

Sample: 50%A2 50%OM
Size: 34.35 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

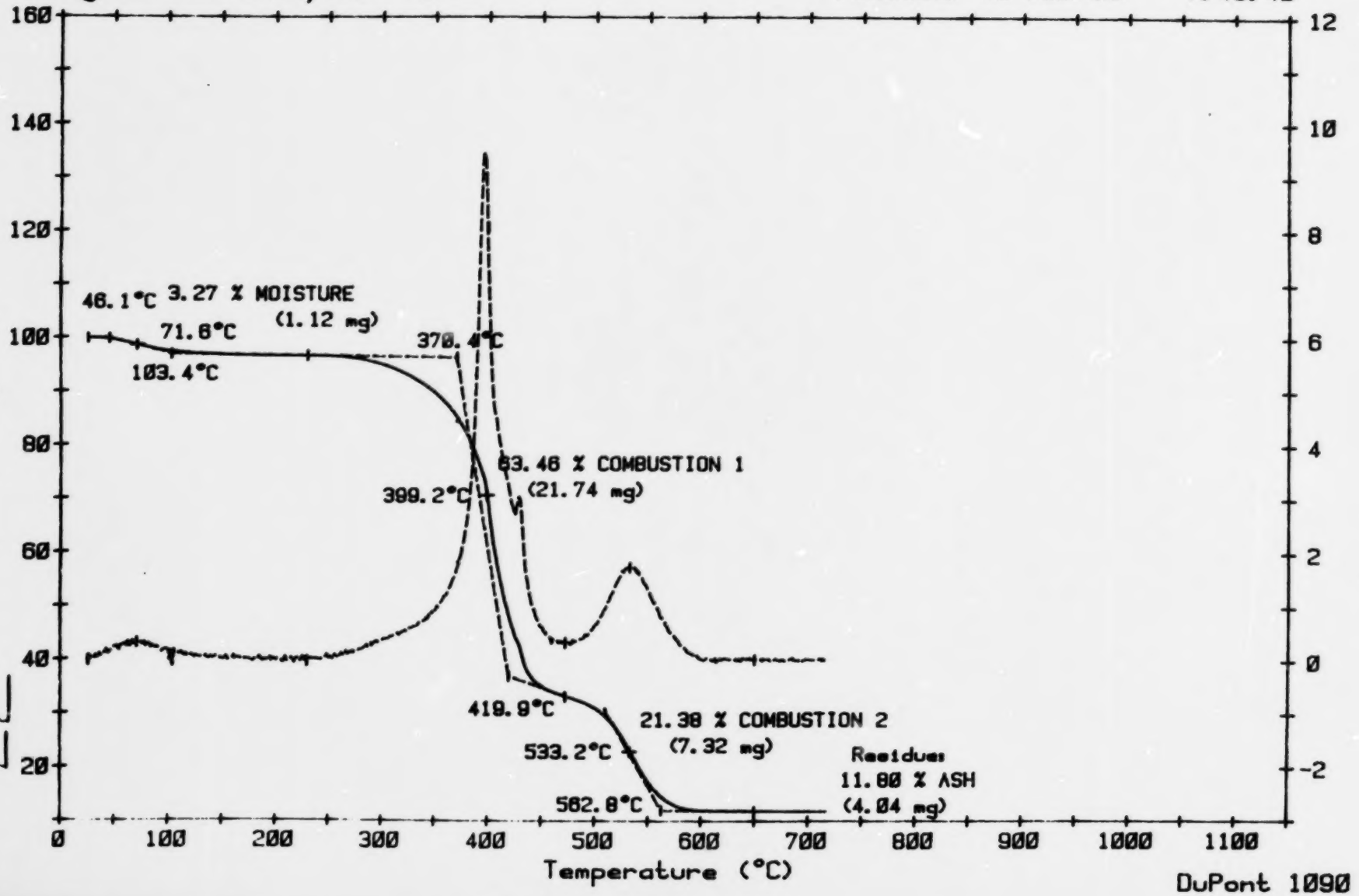
Date: 13-Feb-86 Time: 13:56:56
File: COAL/ANTH.22 COAL TGA/GC.01



Sample: 25%A2 75%OM
Size: 34.26 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

TGA

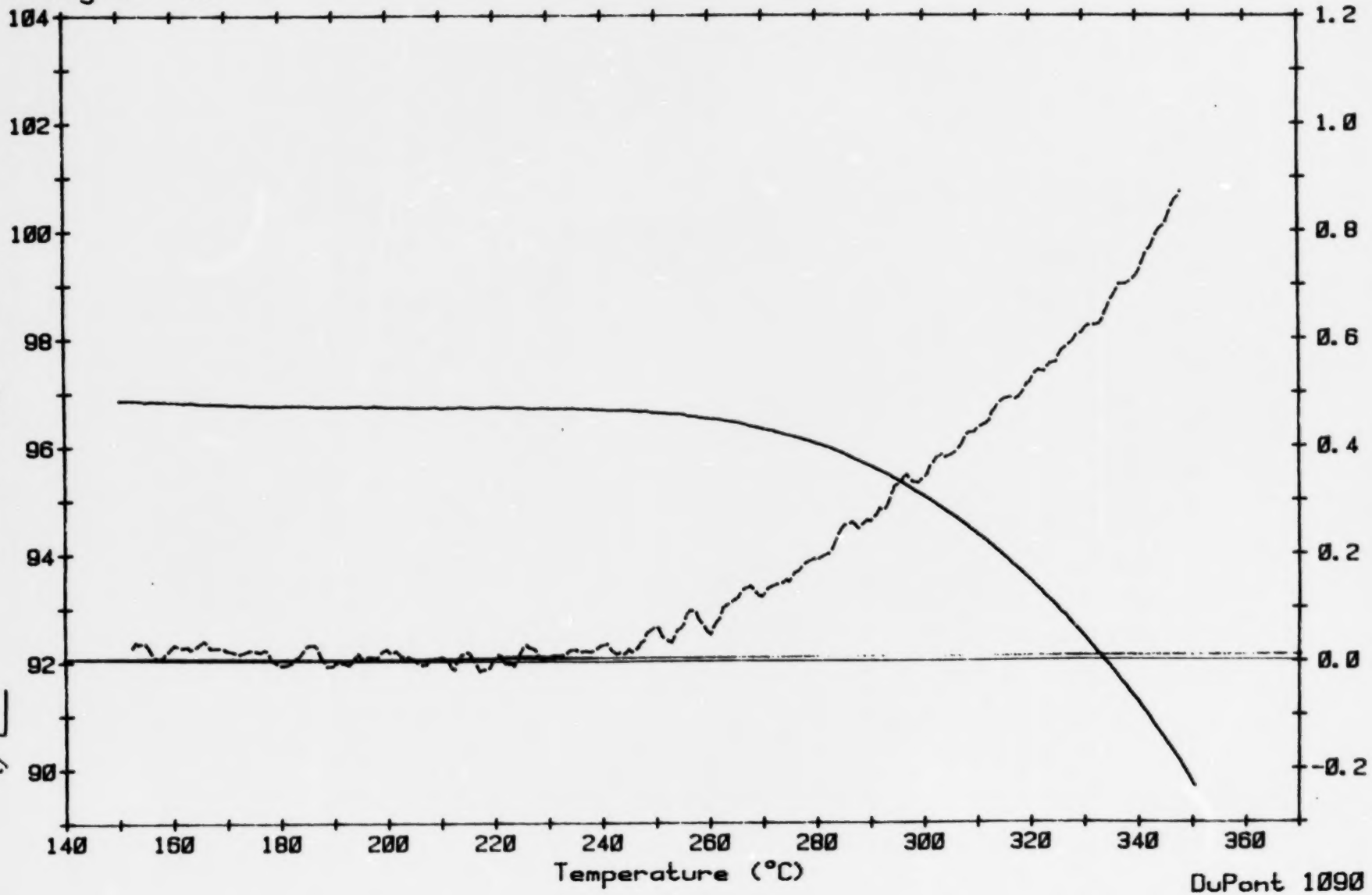
Date: 17-Feb-86 Time: 14:40:21
File: COAL/ANTH.25 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 18-Feb-86 7:46:40



DuPont 1090

Sample: 25%A2 75%OM
Size: 34.26 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA

TGA



DuPont 1090

Sample: 25%A2 75%OM
Size: 34.26 mg
Rate: 5C/MIN 40ML/MIN AIR
Program: TGA Analysis V2.0

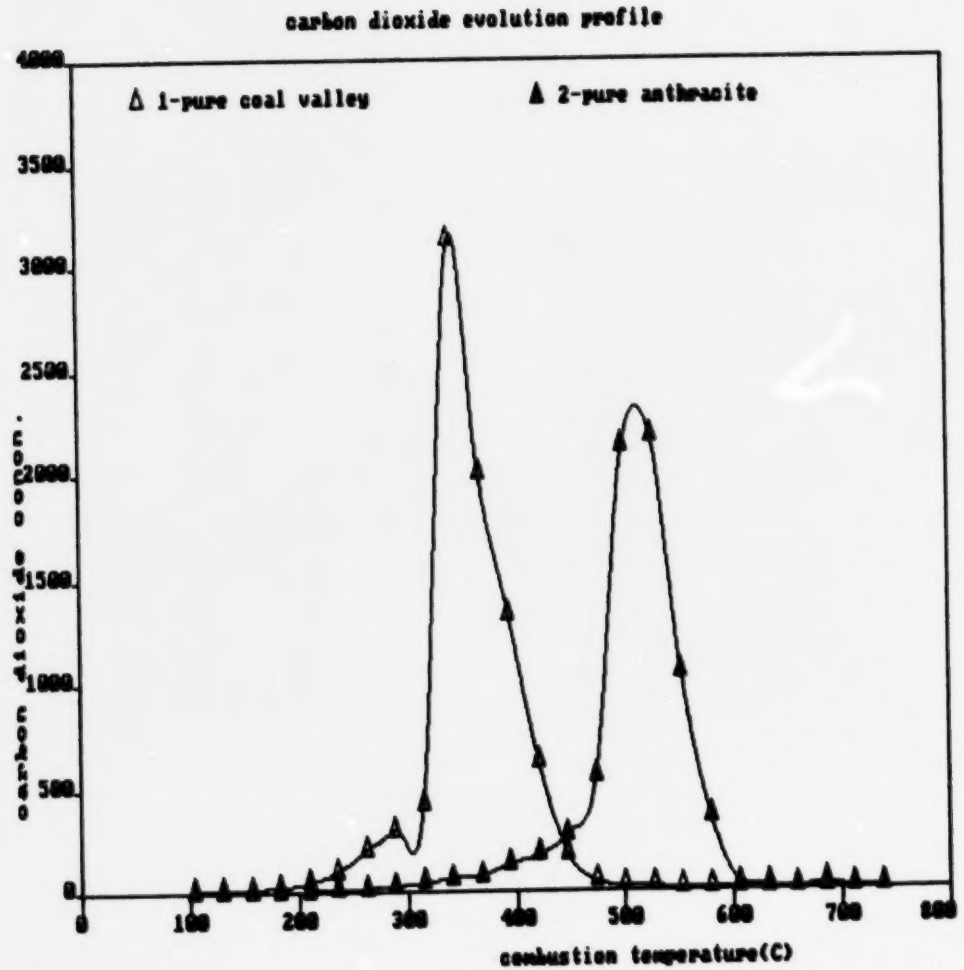
Date: 17-Feb-86 Time: 14:40:21
File: COAL/ANTH.25 COAL TGA/GC.01
Operator: 347-85-85
Plotted: 18-Feb-86 8:53:43

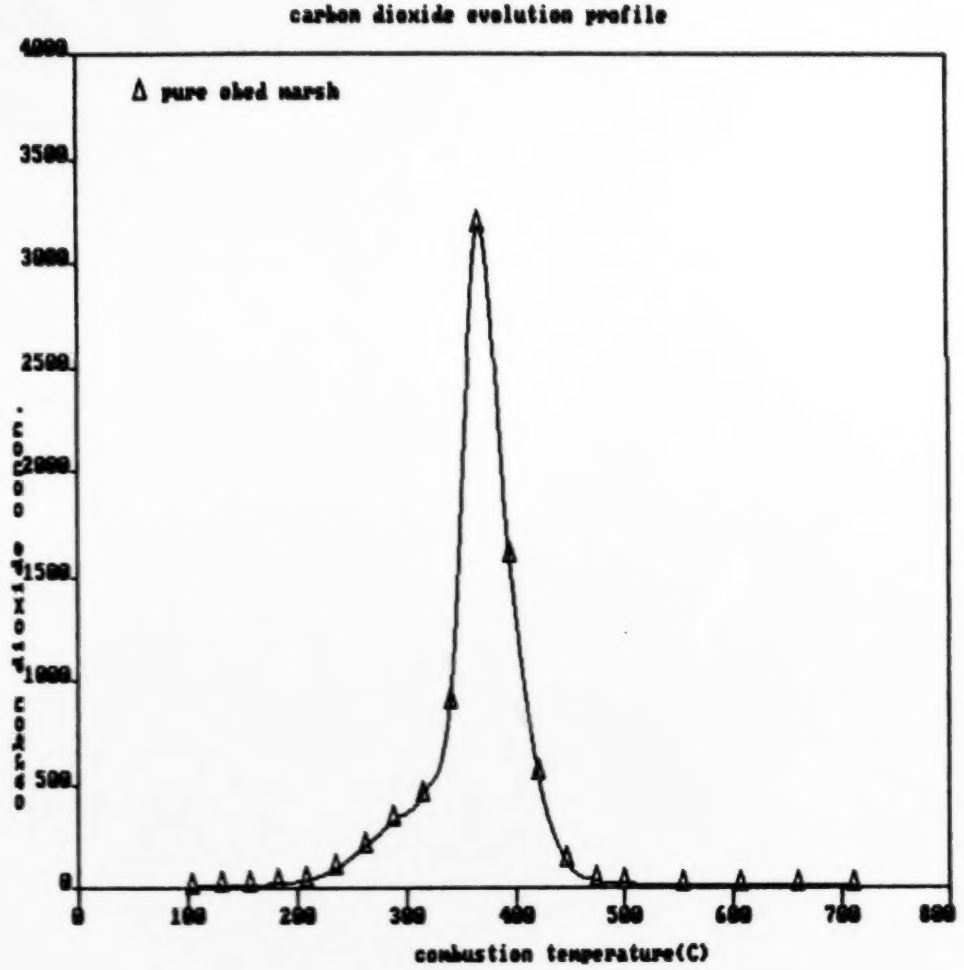
Transition	Onset [°C]	Inflection [°C]	Completion [°C]	Weight [mg]	Weight [%]
MOISTURE	46.1	71.6	103.4	1.12	3.27
COMBUSTION 1	370.4	399.2	419.9	21.74	63.46
COMBUSTION 2		533.2	562.8	7.32	21.38
ASH	Residue at 720.1 °C			4.04	11.80

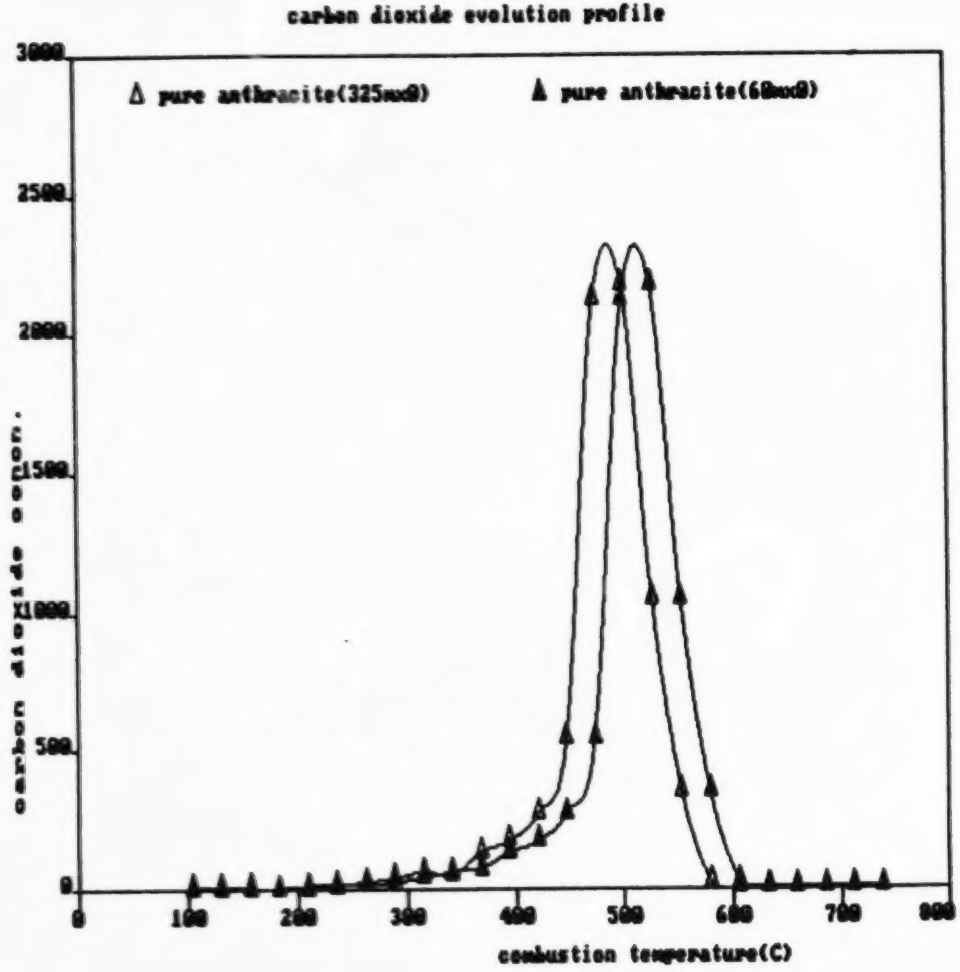
Modified Sample Weight: 34.26 mg

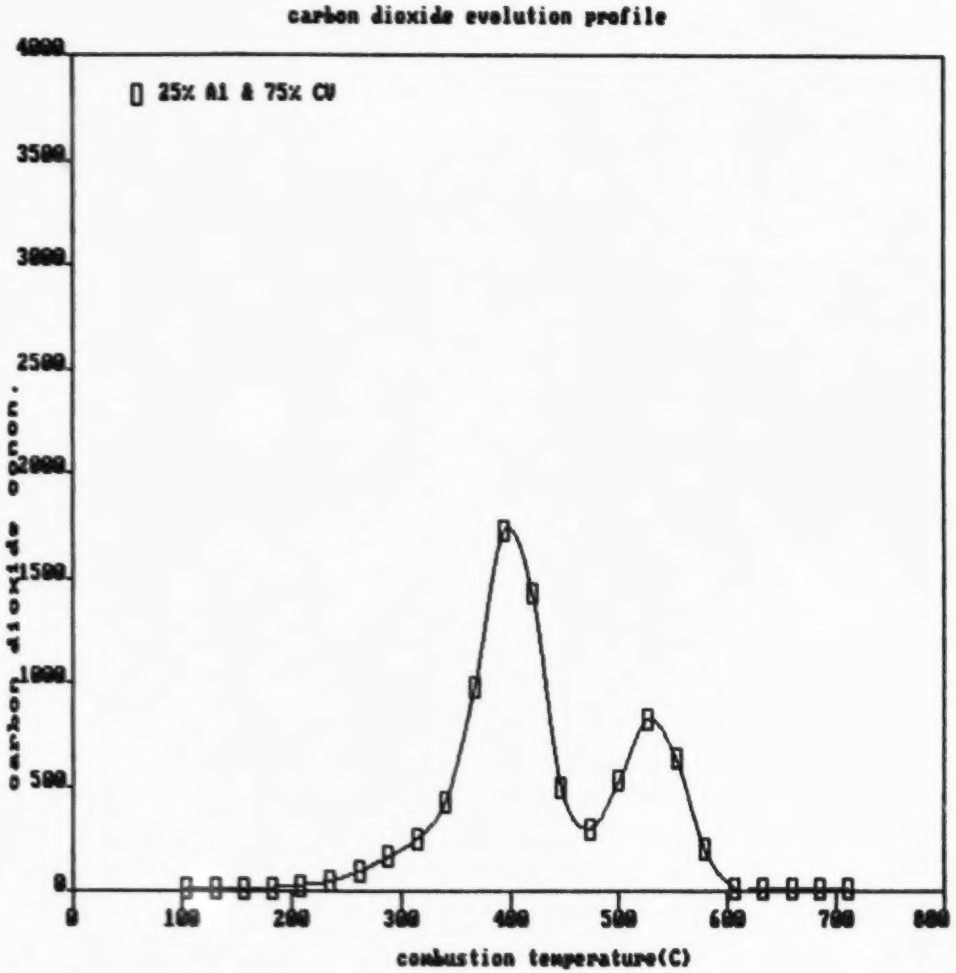
APPENDIX 5

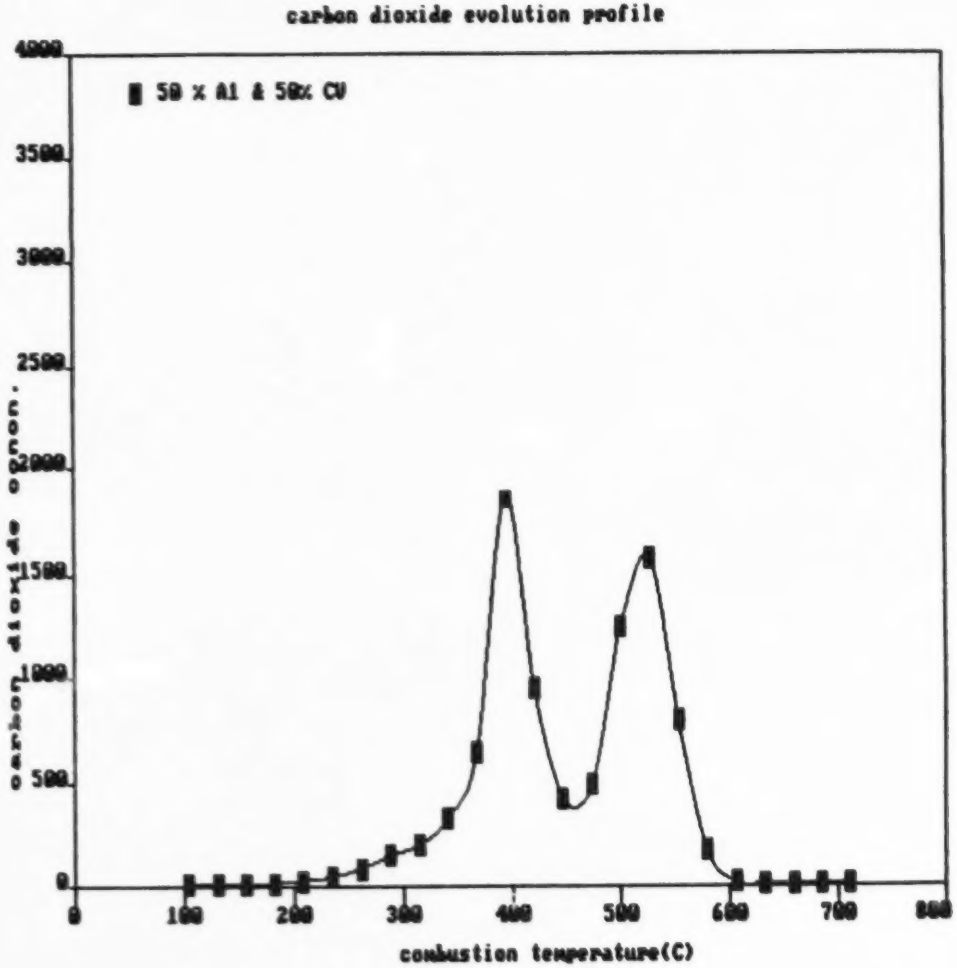
CARBON DIOXIDE EVOLUTION PROFILES


carbon dioxide evolution profile
Δ 1-pure coal valley
▲ 2-pure anthracite
carbon dioxide conc.
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)

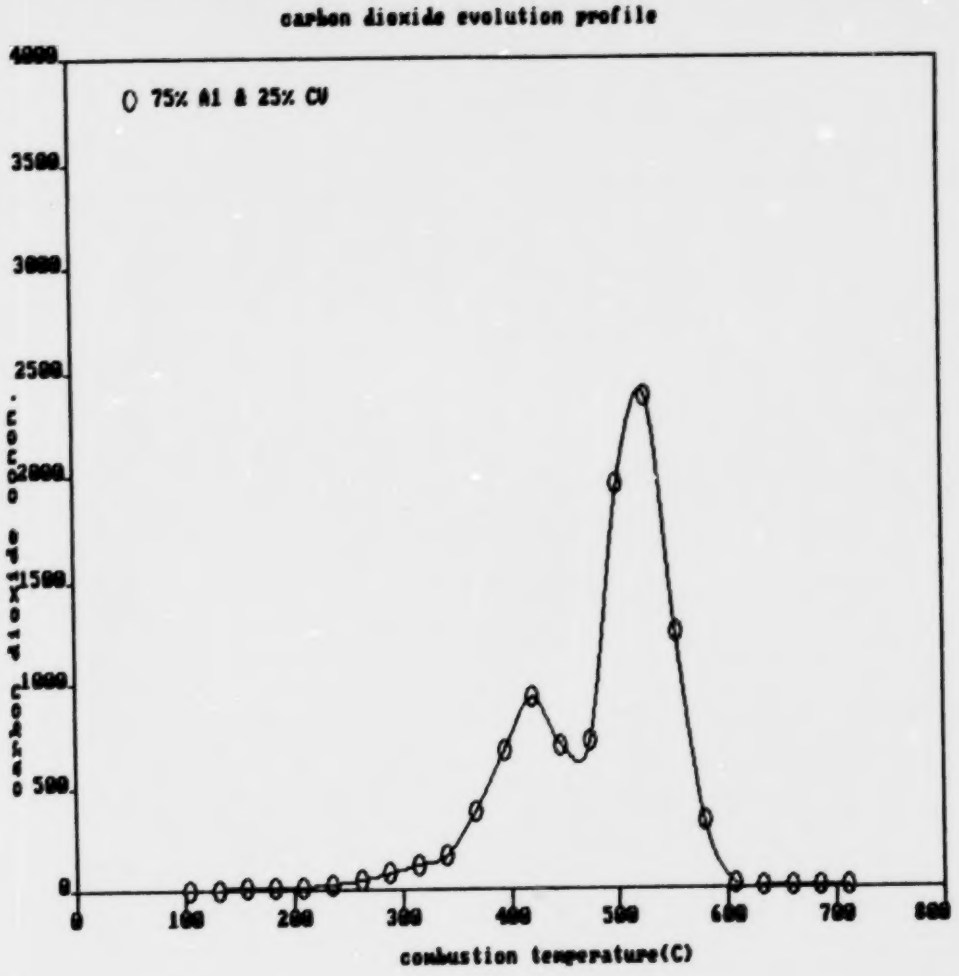

carbon dioxide evolution profile
Δ pure oked marsh
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)

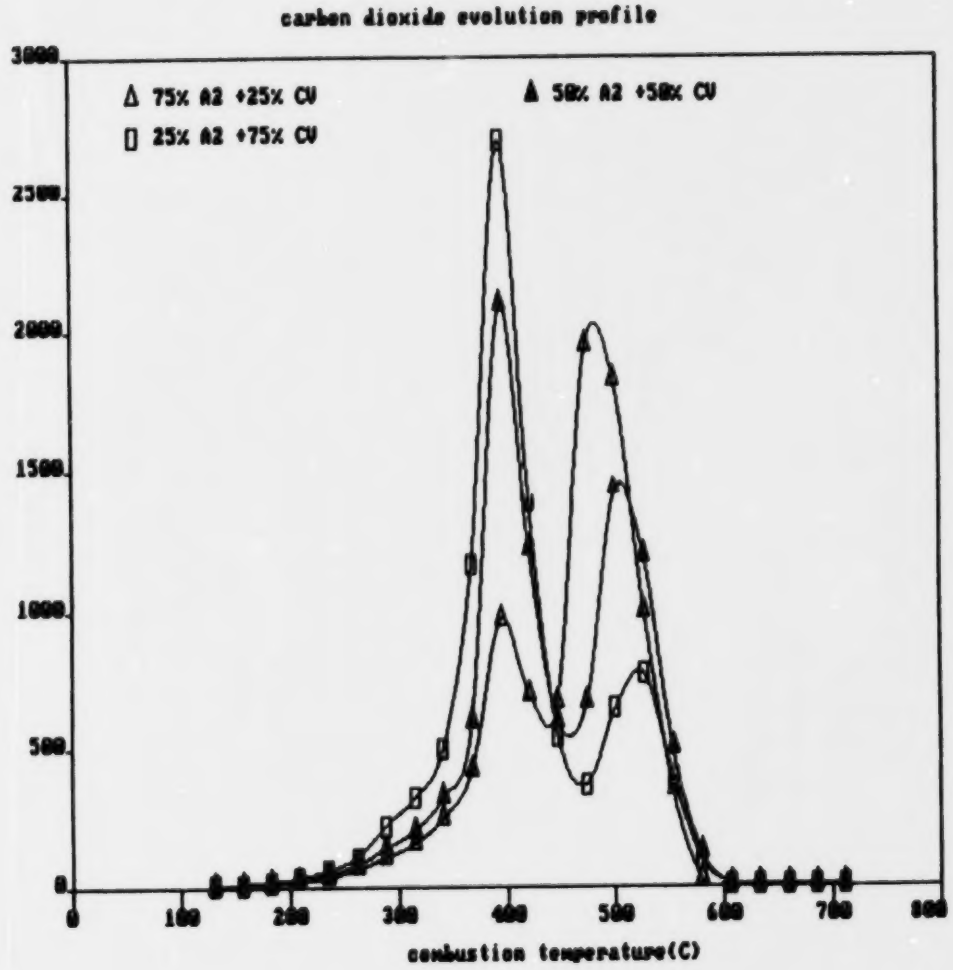

carbon dioxide evolution profile
Δ pure anthracite(325mx8)
▲ pure anthracite(68mx8)
3000
2500
2000
1500
1000
500
0
carbon dioxide concn.
0
100
200
300
400
500
600
700
800
combustion temperature(C)

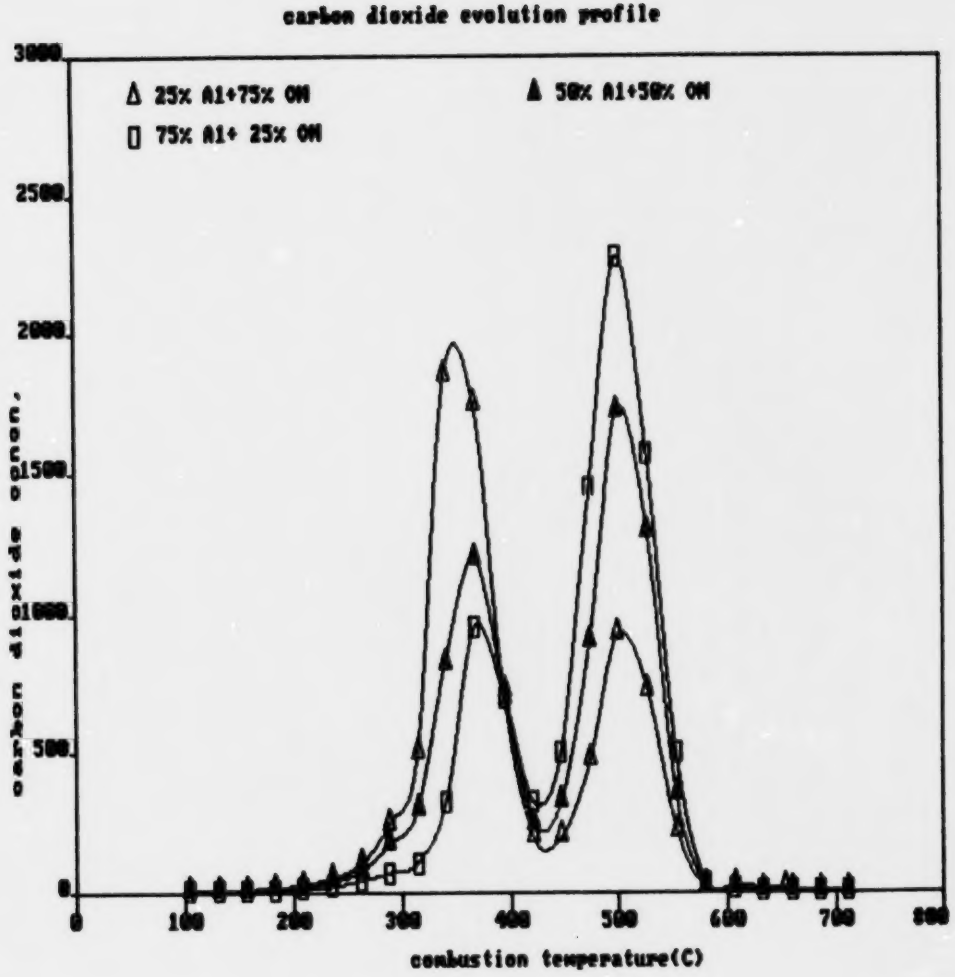

carbon dioxide evolution profile
25% Al & 75% CU
4000
3500
3000
2500
2000
1500
1000
500
0
carbon dioxide concn.
0
100
200
300
400
500
600
700
800
combustion temperature(C)

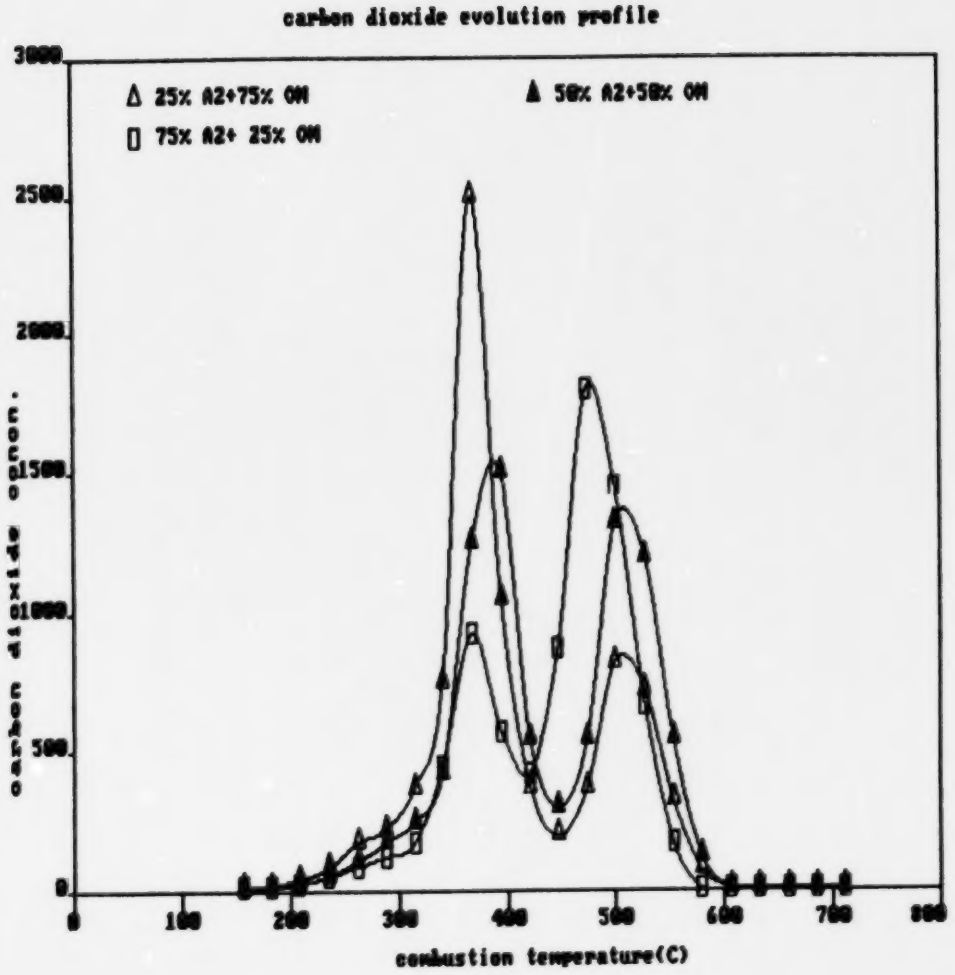

carbon dioxide evolution profile
50 x A1 & 50% CV
carbon dioxide concn.
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)

00


carbon dioxide evolution profile
0 75% Al & 25% Cu
carbon dioxide concn.
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)


carbon dioxide evolution profile
Δ 75% A2 +25% CU
[] 25% A2 +75% CU
▲ 50% A2 +50% CU
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)


carbon dioxide evolution profile
Δ 25% Al+75% OM
▲ 50% Al+50% OM
□ 75% Al+ 25% OM
carbon dioxide concn.
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)


carbon dioxide evolution profile
Δ 25% A2+75% OM
▲ 50% A2+50% OM
□ 75% A2+ 25% OM
carbon dioxide concn.
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
combustion temperature(C)

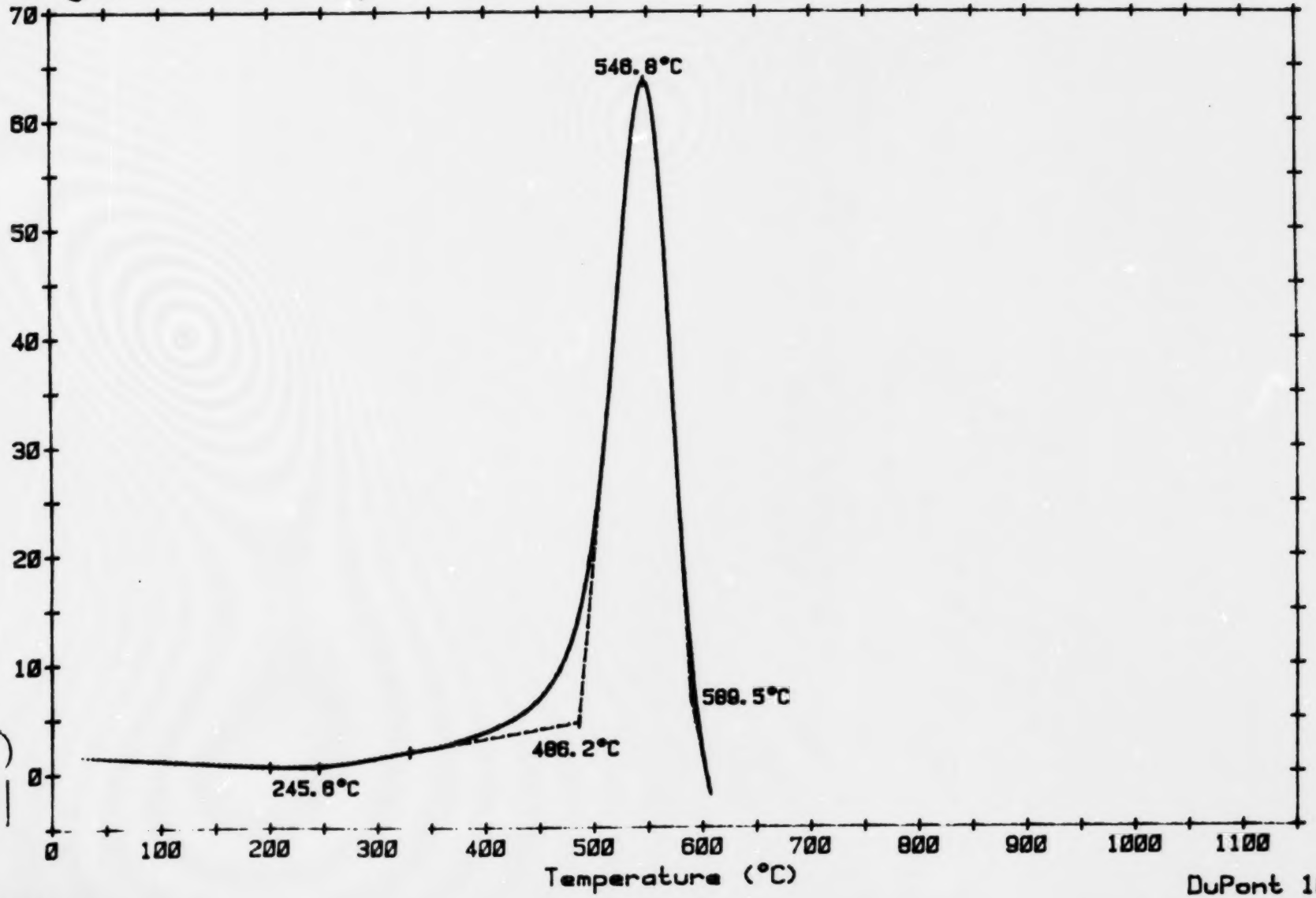
APPENDIX 6

DSC DATA ON COAL AND COAL MIXTURES

Sample: 100% A1
Size: 5.17 MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0

DSC

Date: 26-Feb-86 Time: 10:50:44
File: COAL/ANTH.05 DSC.JT.01
Operator: 347-85-85
Plotted: 26-Feb-86 13:29:42

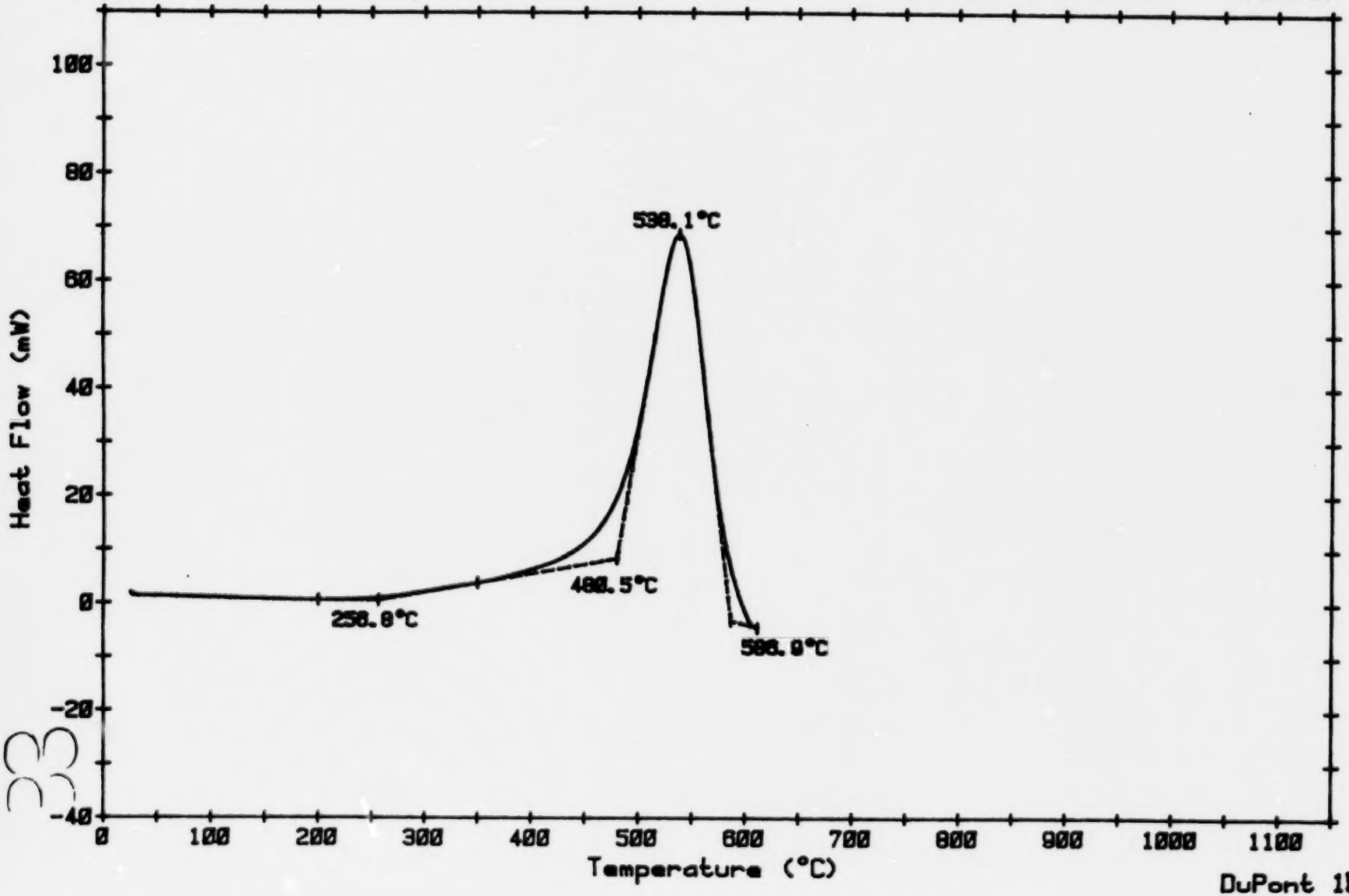


DuPont 1090

Sample: 100% A2
Size: 5.29 MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0

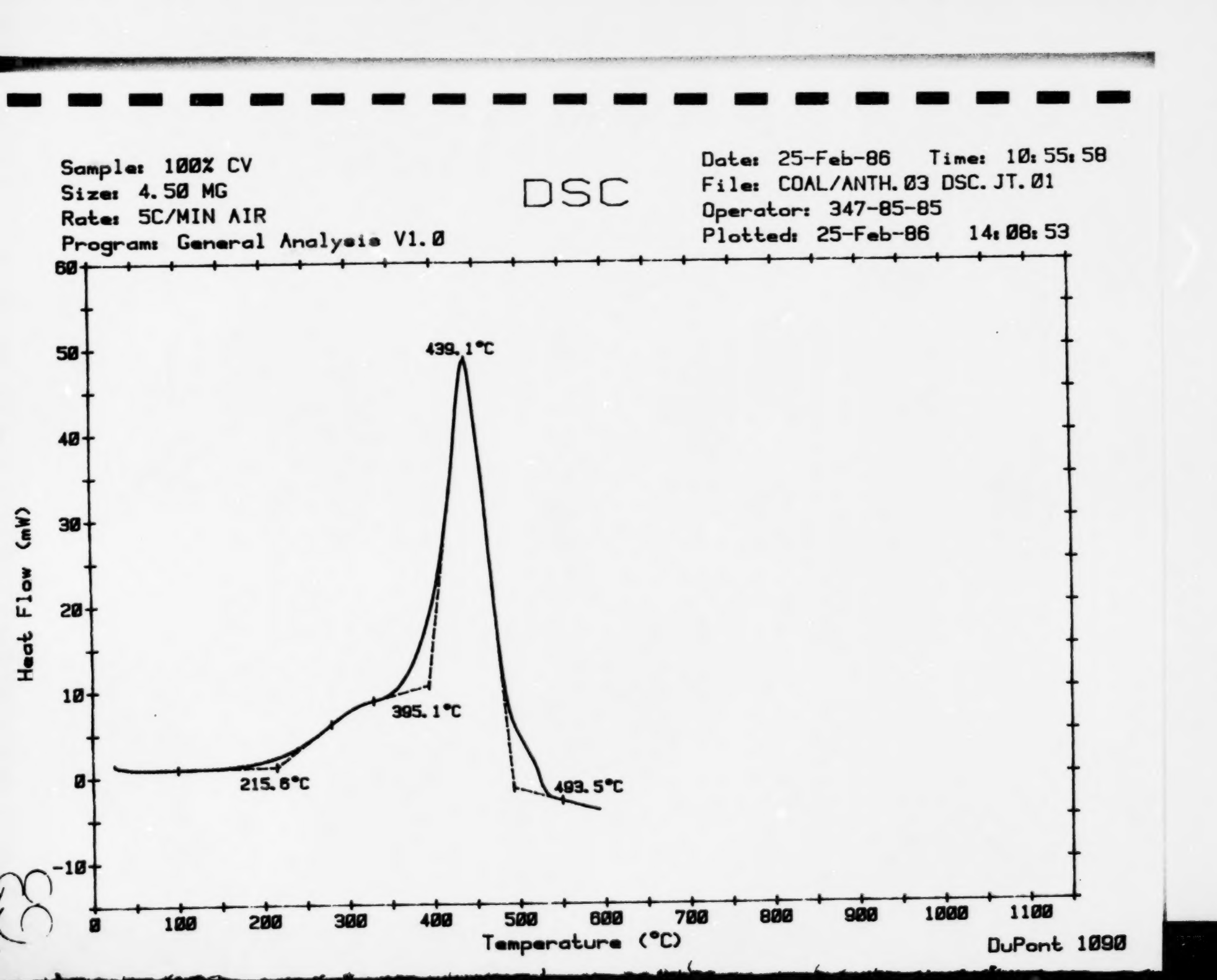
DSC

Date: 26-Feb-86 Time: 14:13:03
File: COAL/ANTH.06 DSC.JT.01
Operator: 347-85-85
Plotted: 27-Feb-86 8:04:57



DuPont 1000

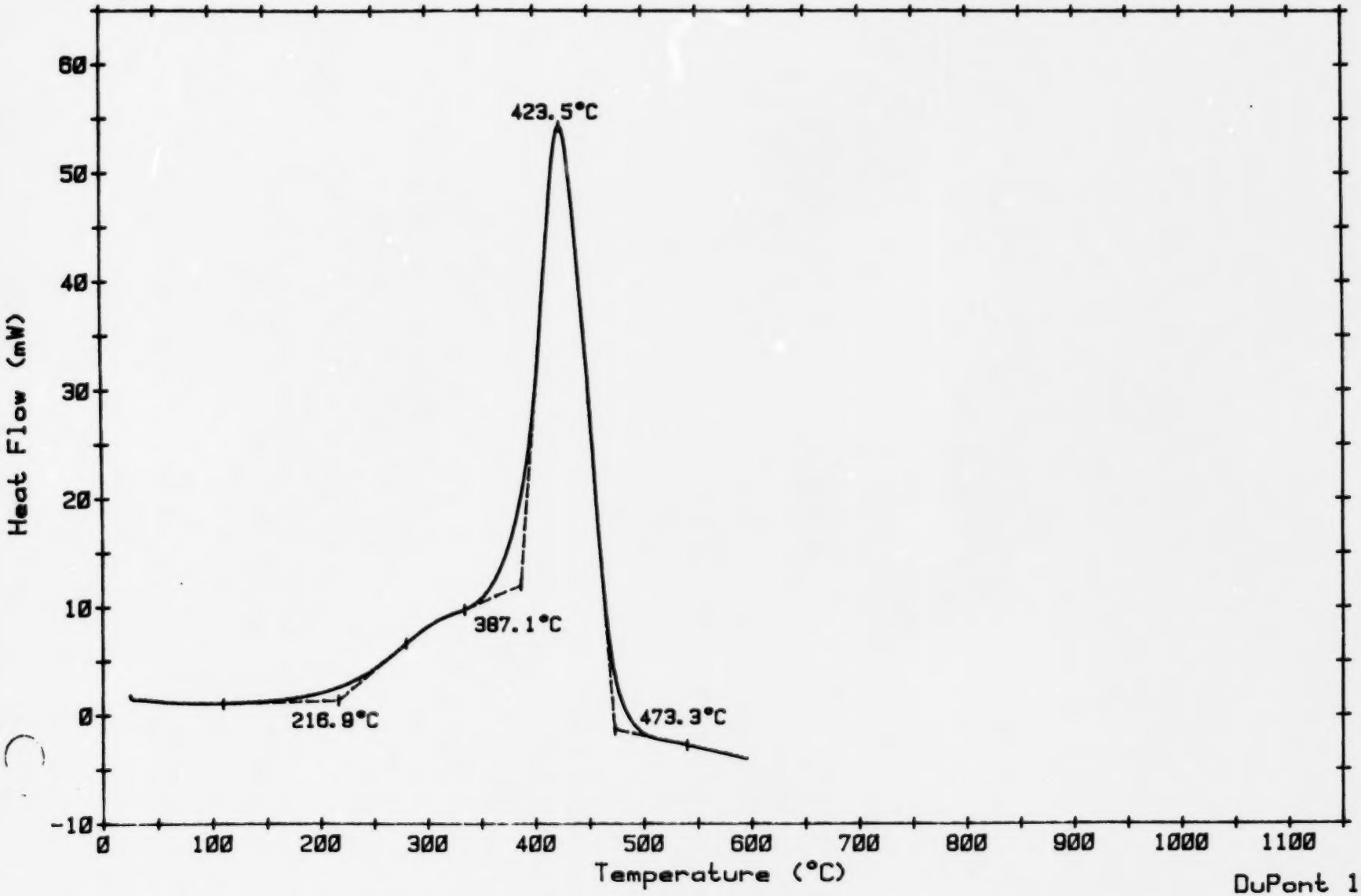
33


Sample: 100% CV
Size: 4.50 MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0
DSC
Date: 25-Feb-86 Time: 10:55:58
File: COAL/ANTH.03 DSC.JT.01
Operator: 347-85-85
Plotted: 25-Feb-86 14:08:53
439.1°C
395.1°C
215.6°C
493.5°C
Heat Flow (mW)
60
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
700
800
900
1000
1100
Temperature (°C)
DuPont 1090

Sample: 100% OM
Size: 3.64 MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0

DSC

Date: 26-Feb-86 Time: 7:47:02
File: COAL/ANTH.04 DSC.JT.01
Operator: 347-85-85
Plotted: 26-Feb-86 9:49:52

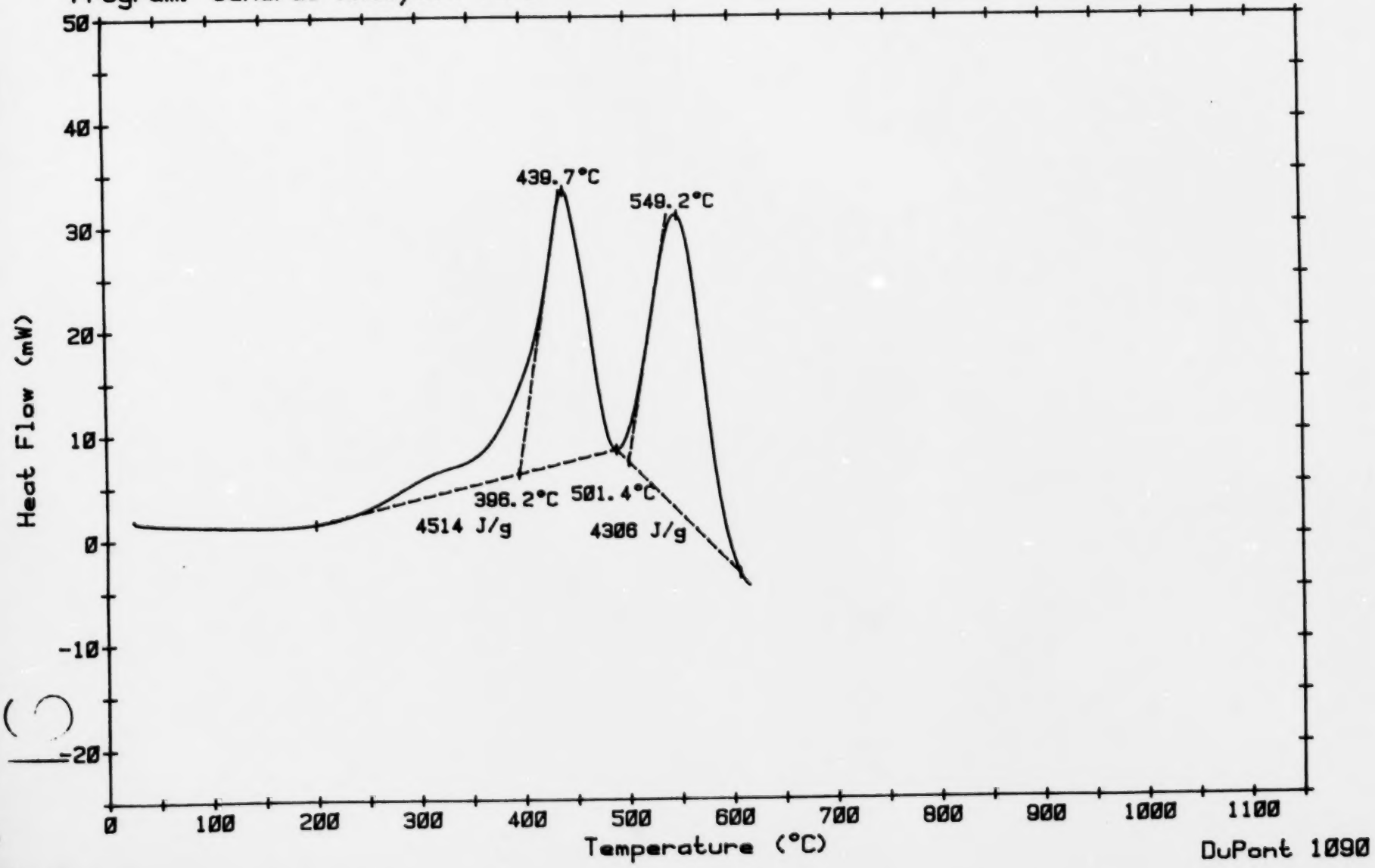


DuPont 1090

Sample: 50%A1 50%CV
Size: 4.50MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0

DSC

Date: 27-Feb-86 Time: 8:58:17
File: COAL/ANTH.07 DSC.JT.01
Operator: 347-85-85
Plotted: 27-Feb-86 14:12:26

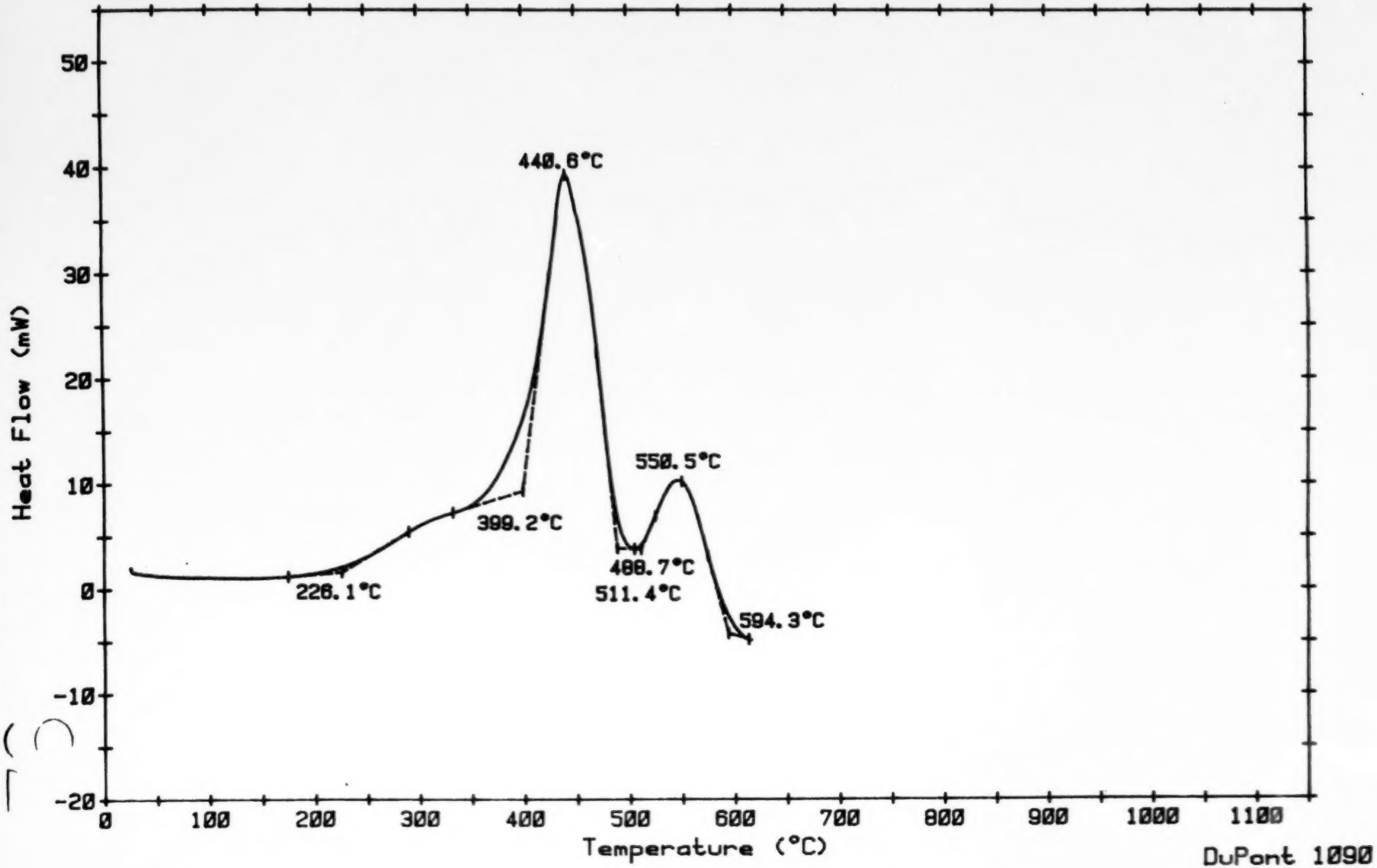


DuPont 1090

Sample: 25%A1 75%CV
Size: 4.15MG
Rate: 5C/MIN AIR
Program: General Analysis V1.0

DSC

Date: 27-Feb-86 Time: 12:36:41
File: COAL/ANTH.08 DSC.JT.01
Operator: 347-85-85
Plotted: 27-Feb-86 16:03:12



DuPont 1090